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JOURNAL

OF

THE ROYAL SOCIETY

OF

WESTERN AUSTRALIA, INC.

Founded 1913 :: :: Incorporated 1937

Vol. XXIV

1937-1938

The Authors of Papers are alone responsible for the statements
and
the opinions expressed therein.

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1938.

THE ROYAL SOCIETY OF WESTERN AUSTRALIA, Inc.

OFFICERS AND COUNCIL, 1937–38.

Patron:
His Majesty the King.

Vice-Patron:
His Excellency Sir James Mitchell, K.C.M.G.,
Lieut.-Governor of the State of Western Australia.

President:
L. J. H. Teakle, M.Sc., Ph.D., A.A.C.I.

Past President:
F. G. Forman, B.Sc.

Vice-Presidents:
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T. H. Wilson.

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Hon. Assistant Librarian:
Eileen A. Bowley, M.Sc.

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R. J. Little.
G. L. Sutton, D.Sc.(Agric.).
E. J. T. Thompson, M.C., M.A., B.Sc., M.B., Ch.B.
R. C. Wilson, B.Sc., B.E.

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VOLUME XXIV.

The Royal Society of Western Australia (Inc.).

ANNUAL REPORT OF COUNCIL FOR THE YEAR ENDED 30th JUNE, 1938.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ended 30th June, 1938.

Patronage of the Society.—His Majesty King George VI., through His Excellency the Lieutenant-Governor, has been graciously pleased to honour the Society by accepting the office of Patron. His Excellency the Lieutenant-Governor, Sir James Mitchell, has accepted the office of Vice-Patron.

Arrangements have been made for an autographed portrait of His Majesty to be hung in the Society's rooms.

Council.—Ten meetings of Council have been held during the year and have been well attended.

Finance.—The General Fund shows a balance of £85 0s. 3d. Against this there are commitments to the Government Printer amounting to £75. The Endowment Fund has been increased to £250. Although this fund is small at present it is hoped that gifts such as that from the late Major Thynne will supplement the resources of the Society in building up this Fund to enable it at some future date to embark upon a suitable housing scheme. The progress already made is due to the careful management of the Society's finances by its Honorary Treasurers, particularly Mr. H. Bowley and Dr. E. M. Watson.

Membership.—There has been a slight decrease in membership during the year. Three ordinary and four associate members have resigned. Dr. D. L. Serventy has been transferred from the roll of ordinary members to that of Corresponding Members. Two associates have been removed from the register in accordance with Rule 6.

We regret to record the loss by death of three of our members. Mr. T. Blatchford and Mr. A. J. Hall were foundation members of the Society, and Dr. F. T. Lovegrove became a member in 1918. These three gentlemen took a keen personal interest in the proceedings of the Society.

Four ordinary and two associate members have been elected during the year.

There are at present 172 members, made up as follows:—

Honorary Members	7
Corresponding Members	8
Ordinary Members	93
Associate Members	54
Student Members	10

Journal.—Volume XXIII. has been published and distributed amongst members and scientific institutions with which the Society is in exchange.

The Government Printer and his staff have co-operated whole-heartedly with the Editor, Mr. B. L. Southern, and the Council desires to thank them sincerely. Mr. Southern remains in the office of Editor and the Society is indebted to him for continuing to place his experience in this work at its disposal.

Library.—Exchange publications now arrive regularly from 169 scientific institutions, 51 of which are in Australia, 16 in the United Kingdom, 21 in other parts of the British Empire, 42 in North and South America, 36 on the Continent of Europe, and 3 in Asia. There is an increasing number of requests that our Journal be exchanged for the publications of scientific institutions in all parts of the world.

During the year Mr. A. Gibb Maitland donated 10 bound volumes of "Nature" to the Society and several bound volumes of the Proceedings of the Royal Society of Queensland. We are now endeavouring to arrange for this series to be made complete.

During the year much needed additional shelving has been provided and this has necessitated reorganisation of the Society's library. Miss E. A. Bowley, who has undertaken the office of Librarian since the departure of Mr. Glauert in March last, has, with the aid of several voluntary helpers, devoted many evenings to this work. The result will facilitate the labour of research workers who, to an ever-increasing extent, are finding themselves dependent upon the Society's library for many publications which are unobtainable elsewhere in this State.

Award of the Kelvin Medal of the Royal Society of W.A.—The award for 1936-37 was made to Mr. A. Gibb Maitland, F.G.S., and this was presented to him in October by Sir George Julius, Chairman of the Council for Scientific and Industrial Research, at a conversazione held in Winthrop Hall conjointly with the University.

Recognition of Services of Mr. L. Glauert.—Mr. Glauert, Hon. Librarian and a Past President of the Society, departed overseas in March on a tour of America, England, and Europe. Prior to his departure he was made the recipient of a handsome fountain pen, suitably inscribed, as a token of his many years of service to the Society.

Incorporation.—Early in the financial year the incorporation of the Society was completed. The Society is deeply indebted to the Hon. John Nicholson, M.L.C., for his assistance in this matter.

Endowment Land.—In accordance with advice tendered by members of the State Legislature who had been approached, it has been decided to defer the approach to the Government concerning a request for a block of land until such time as the Council is in a position to put forward a building scheme.

L. J. H. TEAKLE,
President.

L. W. PHILLIPS,
G. R. W. MEADLY,
Joint Hon. Secretaries.

ROYAL SOCIETY OF WESTERN AUSTRALIA, INCORPORATED.

Statement of Receipts and Expenditure for the Year ended 30th June, 1938.

Receipts.

	£ s. d.
General Fund—	
Balance at 1st July, 1937	147 1 5
Interest, 1936–37	2 6 6
Subscriptions	132 6 6
Government Grant	100 0 0
Authors' Reprints and Half Cost of Blocks	20 12 10
Members' Contributions (Presentation Fund)	1 15 0
Sale of Journal	0 10 4
Interest on Fixed Deposit	7 18 4
Transfer from Medal Fund	15 15 0
Adjustment of Cost of Conversazione	5 8 0
	£433 13 11
Medal Fund—	
Balance at 1st July, 1937	30 17 7
Interest, 1936–37	0 11 6
Transfer from General Fund	2 10 0
	£33 19 1
Endowment Fund—	
Balance at 1st July, 1937	176 4 11
Interest	10 11 1
Transfer from General Fund	63 4 0
	£250 0 0

Payments.

	£ s. d.	£ s. d.
General Fund		
Petty Expenses, including Postages, etc.		17 6 10
Clerical Assistance		6 11 6
Museum Trustees—Rent and Attendance		24 6 0
Ordinary Meetings—Catering		10 2 6
Incorporation Expenses (Balance)		10 18 0
Conversazione		20 0 0
G.P.O. Box L906—Rent		3 0 0
Library—Shelving	18 17 6	
,, Cases	0 13 6	
		19 11 0
Presentation		3 10 0
Transfer to Medal Fund		2 10 0
Transfer to Endowment Fund	63 4 0	
,, ,, ,, ,, Interest	7 18 4	
		71 2 4
Kelvin Medal Award		15 15 0
Government Printer—		
Vol. 23, completing	66 6 8	
Vol. 24, part cost	48 7 10	
Miscellaneous printing	7 2 0	
		121 16 6
Cost of Preparation of Blocks		5 4 0
Editor's Honorarium		15 15 0
Other Printing		1 5 0
Balance at 30th June, 1938		85 0 3
		£433 13 11
Medal Fund		
Striking of Medal		0 18 4
Engraving of Medal		0 7 6
Award (Mr. A. Gibb Maitland)		15 15 0
Balance in Bank, 30th June, 1938		16 18 3
		£33 19 1
Endowment Fund		
Balance at 30th June, 1938		250 0 0
		£250 0 0

Note.—£250 placed on fixed deposit at Commonwealth Bank, Perth, on 13th June, 1938, for 24 months, bearing interest at 3% per annum.

Summary of Funds at 30th June, 1938.

	£ s. d.
Credit Balance, General Fund	85 0 3
,, ,, Medal Fund	16 18 3
,, ,, Endowment Fund	250 0 0
	£351 18 6

1st July, 1938.

E. M. WATSON, Hon. Treasurer.

Audited and found correct, with books, receipts and vouchers produced, and we consider this a true statement of the Royal Society's Accounts.

R. E. GATHERER,
H. P. ROWLEDGE,
Hon. Auditors.

The Royal Society of Western Australia, Incorporated.

CONSTITUTION

AND

RULES AND REGULATIONS

CONSTITUTION.

1. A Society is hereby established under the name of "THE ROYAL SOCIETY OF WESTERN AUSTRALIA INCORPORATED" (hereinafter referred to as "the Society") with the objects and for the purposes hereinafter mentioned.

OBJECTS AND PURPOSES.

1. To acquire all the assets and property of every description belonging to the Body or Society heretofore known as "THE ROYAL SOCIETY OF WESTERN AUSTRALIA" hereinafter called "the Old Society," and to assume and take over all the liabilities of the old Society, and for all or any such purposes to enter into such agreements or writings as the Council hereinafter referred to may at any time determine or resolve.

2. To promote and to assist in the advancement of science in all its branches.

3. To found, subsidise, or contribute to any institution or person scholarships, grants, prizes, or monetary or other reward in connection with all or any of the objects or purposes herein.

4. To promote, produce, and hold or join in promoting, producing, and holding any exhibitions, lectures, or any form of study or entertainment in furtherance of any objects of the Society or for the purpose of inducing interest in the objects or work of the Society, or in raising funds for its benefit or of any object thereof.

5. To establish schools or institutions for study or research in connection with any scientific subject or subjects, and to maintain the same and pay and disburse all or any expenses in connection therewith.

6. To protect or assist in protecting the interest or rights of any member or members of the Society, as the Council or the Society in General Meeting may from time to time decide, and to take or join with any other person or body in any action, steps, or proceedings from time to time deemed expedient.

7. To acquire by purchase, lease, exchange, hire, or by way of loan or otherwise, any real or personal property.

8. To sell, lease, hire, mortgage, charge, lend, surrender or otherwise dispose of, or deal with all or any part of the assets or property, real or personal, of the Society, and to borrow money upon such terms as the Council may think proper for the purposes of the Society, and to grant security therefor and to liquidate, redeem, or discharge any obligations undertaken.

9. To improve, develop, or extend all or any of the property or rights of the Society, also to build, erect, or alter any buildings or erections, and to furnish, fit up, and maintain the same and provide such fittings, equipment, appliances and conveniences as may be deemed proper.

10. To print and publish, or join in printing and publishing, one or more newspapers, periodicals, books, journals, or other documents that the Council, or the Society may from time to time think desirable.

11. To amalgamate, co-operate, or affiliate with any other Society, Association, or Body having objects wholly or in part similar to those of this Society.

12. To assist in or subscribe to any scientific, charitable, patriotic, educational or public purpose or any fund which may be raised for the benefit or assistance or commemoration of any person, Society, or Association.

13. To invest any moneys of the Society in such manner as may from time to time be determined by resolution of the Council or by the Society in General Meeting.

14. To carry out all or any objects or purposes which may be or may be deemed to be incidental to the foregoing, and also all or any objects or purposes which may at any time or times be agreed to or passed by any resolution of the Society in General Meeting.

RULES AND REGULATIONS.

MEMBERSHIP.

1. The Society shall consist of members divided into the classes hereinafter mentioned and the members who are, have been, or may be duly elected as members of such respective classes shall have the rights and privileges hereinafter specified as appertaining to such respective classes, subject always to the due and punctual payment of the annual subscription or other sum hereinafter provided to be paid by the respective members of each class, namely :—

(*a*) Ordinary members shall include all persons who according to the books or records of the Old Society have been elected and are at the date of incorporation hereof members of such last-mentioned Society, and also all persons who may after the date of incorporation hereof be elected as ordinary members of the Society. Each ordinary member shall have the following rights and privileges :—

(i) To be present and to speak and vote at General Meetings of the Society and to attend excursions from time to time held in connection with the work of the Society.

(ii) To be eligible for election as a member of the Council hereinafter referred to and also to any office or position in the Society.

(iii) To submit to the Council papers prepared by any such member on any scientific or other subject approved by the Council for communication to the Society and subsequent publication, if approved by the Council.

(iv) To communicate to the Society through the Council, on behalf of authors not resident in Western Australia, papers written by such authors dealing with subjects connected with Western Australia.

(v) To receive the Journal and Proceedings of the Society as may from time to time be issued by the Society, and such other publications of the Society as and upon such conditions as the Council may from time to time determine.

(vi) To nominate, propose, or second candidates for admission as Ordinary Members, Associate Members, or Corresponding Members.

(vii) Subject to the approval of the Council to borrow any books, papers, manuscripts, or publications belonging to the Society.

(viii) With the previous approval or assent of the Council, or President or Chairman of any meeting, to introduce visitors to such number from time to time as may be approved or permitted at any of the meetings and excursions of the Society, but so that such visitors shall only be entitled to attend for the purpose of hearing any discussion which may take place, or lecture which may be given at any such meeting, and shall not be entitled to vote, but may with the consent or on the invitation of the Chairman of the meeting, speak or give expression to his or her views on the subject under discussion.

(b) *Associate Members.*—Persons elected as Associate Members shall be entitled to attend and speak at general meetings and excursions of the Society, but shall not be entitled to vote at any meeting, and if any such member should vote then the vote shall not be counted. Further, such members shall not be entitled to be nominated for, or elected to, any office in the Society, nor submit papers for publication. Such members shall be entitled to receive a copy of the Society's Journal at a price to be fixed by the Council from time to time, and, subject to the approval of the Council, may borrow any books, papers, manuscripts, etc., belonging to the Society.

(c) *Student Members.*—The Council may, on application to be made in such form as may be from time to time required by the Council, elect as Student Members for a period of twelve months only, dating from the 1st day of January in the year of application, persons under the age of twenty-five years attending recognised Science classes in Western Australia. Such members shall only be entitled to attend meetings and excursions of the Society and shall not be entitled to vote at any such meeting nor to any of the privileges of other classes of members. Student Members may consult but not borrow the contents of the Society's library.

(d) *Corresponding Members.*—Persons not resident in Western Australia who may desire to promote the objects of the Society may be elected as Corresponding Members, such membership to continue so long as such member shall be resident outside of Western Australia or until such time as the Council may determine such membership; and if such member should take up residence in Western Australia then the membership of such person shall thereupon cease. Each Corresponding Member shall be entitled to enjoy the same rights as Ordinary Members in respect of the publications of the Society, and may,

on application to the Council, be elected as an Ordinary Member, subject to payment of the subscription payable by each Ordinary Member. No person shall be elected as a Corresponding Member unless he shall first have been nominated on the prescribed form by three or more Ordinary or Honorary Members of the Society and be known to one at least of such members. Corresponding members shall not be liable for any subscription.

(*e*) *Honorary Members.*—The Society, at its Annual General Meeting in any year, may, on the recommendation of the Council, elect from time to time as Honorary Members persons distinguished in science, or as patrons thereof, but so that the number of such members shall not at any time exceed twenty-five. Persons elected as Honorary Members shall be entitled to enjoy the same privileges as Ordinary Members but without liability for any subscription.

2. Every person desirous of becoming an Ordinary, Associate, Student, or Corresponding Member of the Society shall make application in the prescribed form and give such particulars as the Council may require, and be proposed in writing by one Ordinary or Honorary Member to whom the applicant is known personally, and seconded by at least two other members who must be either Ordinary or Honorary members of the Society ; and every such application shall be accompanied with the subscription applicable to the class of membership for which application may be made, and shall be lodged with the Secretary of the Society, whose duty it shall be to submit the application in the first place to the Council of the Society for its approval, and if the Council shall approve of same the Secretary shall thereafter cause each such application to be brought before the Ordinary General Meeting following the approval thereof by the Council and the same shall be read at such meeting, and thereafter particulars of such application shall be posted in some Common Room of the Society and the applicant shall be balloted for at the Ordinary General Meeting of the Society following the meeting at which such application may have been read. If at such last-mentioned meeting three-quarters of the persons present and entitled to vote shall vote in favour of the person so applying, then such person shall be declared to be duly elected. If the person applying shall be duly elected, then notice thereof together with a copy of the rules shall forthwith thereafter be transmitted to such person by the Secretary.

3. Every person so elected shall be bound to observe and perform and not commit any breach of the rules and regulations of the Society from time to time in force.

4. Every member shall, on being elected, notify the Secretary in writing of the address to which he may desire notices or communications forwarded to him, and shall from time to time notify in writing any change in such address ; and if any member shall fail to give such notification he shall not be entitled to receive notice of the meetings or other proceedings of the Society ; and no meetings or other proceedings shall be invalidated by reason of any such member not having received such notice as aforesaid.

5. Any member, on paying to the Society all subscriptions or moneys due by him and returning all books, papers, manuscripts, or property of the Society which may have been borrowed or received by him, may resign his membership by giving notice in writing to the Secretary of the Society ; and any member ceasing by resignation, death, or otherwise to be a member of the Society shall not, nor shall his representatives have any claim upon or interest in the funds or property of the Society ; but nothing herein contained shall prejudice the right of the Society to recover any moneys owing or property of the Society borrowed, held, or received by such member at any time.

6. Any member whose subscription may be in arrear for a period of at least two years shall, on a resolution of the Council being at any time thereafter passed, be declared to be no longer a member and thereupon shall cease to have the rights and privileges to which he may have been entitled ; provided always that nothing herein contained shall prejudice the right of the Society to recover from such member all moneys or subscriptions due, owing, or payable by him up to the date of such determination of his membership, and also to recover all books, papers, manuscripts, or property belonging to the Society which may be held or have been received by such member at any time.

7. Every member in the respective classes of membership in the Society shall use his best efforts to promote the objects of the Society and shall not do or commit any act, deed, or thing which may be deemed by the Council to be prejudicial to the interests of the Society.

8. The Council may, by an affirmative vote of two-thirds of its total membership, remove or suspend from membership or expel any member of the Society without being required to assign any reason for such action. Notice of such removal, suspension, or expulsion, shall be sent by registered post to the member concerned within seven days after the decision of the Council. Any member against whom any such decision of removal, suspension, or expulsion shall be made, shall be entitled to appeal to a General Meeting of the Society by notice to be forwarded by him in writing, addressed to the Secretary within two months after the date of such removal, suspension, or expulsion, stating in such notice the grounds of appeal. It shall be the duty of the Council to summon a Special General Meeting of the Society for the purpose of considering any such appeal, and of hearing statements by any Member of the Council or by the member who may have been removed, suspended or expelled, and if a majority of the members present at such meeting uphold the decision of the Council, then the decision of the Council shall be confirmed, but if such majority shall uphold the appeal, then the decision to remove, suspend, or expel such member shall be set aside. No such member shall be entitled to exercise such right of appeal after the expiration of the said period of two months. In the event of any such removal, suspension, or expulsion taking effect, the member concerned shall remain liable for all moneys or subscriptions due or payable by him as at the date of such removal, suspension, or expulsion, and for the return of all property belonging to the Society.

SUBSCRIPTIONS.

9. The subscription for each Ordinary Member who has his residence or principal place of residence within a circle having a radius of 25 miles from the General Post Office, Perth, shall be One guinea per annum: Provided that if any member shall, at any time before the expiration of the first six months of any year, remove his residence to some place outside the area above specified, or be required in the course of his work, profession, or occupation to reside at some place or places outside such area for a period of at least six months in any year, then such member may make application to the Council for a rebate or reduction in such members' subscription, and the Council shall be empowered to make such rebate or reduction in each case, and that for such period and to such amount as may be determined by the Council. The subscription for each Ordinary Member resident outside the area above specified, shall be Ten shillings and sixpence per annum. Any Ordinary Member whose subscription is not in arrear may at any time compound for the subscription for the current year and for all future years during the life of such member on payment of (*a*) Twenty guineas or (*b*) such sums as will together with the annual subscriptions already paid, make a total of Thirty guineas.

10. The subscription of each Associate Member shall be One-half guinea per annum.

11. The subscription of each Student Member shall be Five shillings per annum.

12. Honorary and Corresponding Members shall be exempt from payment of any subscription.

13. The financial year of the Society shall be from the First day of July in each year to the 30th day of June in the following year.

14. All subscriptions shall be payable in advance and shall become due on the 1st day of July in each year, with the exception of subscriptions of Student Members, which shall become due on the 1st day of January in each year: provided that in the case of members other than Student Members elected at any time during the latter six months of the Financial year, the subscription required to be paid by them respectively in advance shall be one-half of the annual subscription appertaining to the class to which each is elected in respect of the then current financial year.

MANAGEMENT.

15. The management of the business and affairs of the Society shall be vested in a Council consisting of a President, two Vice-Presidents, and also members holding office in each year, respectively, as Honorary Treasurer, Honorary Secretaries, Honorary Librarian, Honorary Editor, also the Immediate Past President and eight Ordinary Members.

The following persons, namely:—F. G. Forman, L. J. H. Teakle, E. S. Simpson, H. Bowley, W. E. Shelton, L. W. Phillips, L. Glauert, B. L. Southern, E. de C. Clarke, H. W. Bennetts, E. A. Bowley, G. A. Elliott, C. A. Gardner, C. F. H. Jenkins, D. L. Serventy, E. M. Watson, T. H. Wilson, who constitute the Council of the Old Society shall be the members of the First Council of the Society and shall hold office until the 30th day of June, 1937, or until their successors be appointed.

16. The persons for the time being holding the respective offices of President, Vice-Presidents, Treasurer, Secretaries, Librarian, Editor and Immediate Past President shall by virtue of their office be members of the Council, but the eight other members of the Council shall be elected annually at the Annual General Meeting of the Society, to be held at a date to be fixed by the Council in the month of July in each year, at which meeting the persons to hold the offices aforesaid shall also be elected. For the purpose of such election the Council then in office shall submit at the Ordinary General Meeting, in the month of June preceding the Annual General Meeting in each year, a list of the names of members nominated by the Council for election for the ensuing year and shall include therein the names of the persons recommended by the Council for the offices of President, Vice-Presidents, Treasurer, Secretaries, Librarian and Editor and (unless the then President is recommended for re-election) shall also include the name of the then President, or failing him, of his predecessor or one of his predecessors in office to hold office as Immediate Past President. Any member present and entitled to vote at such meeting in the month of June may propose or nominate another qualified member to hold any office as aforesaid, or as a Member of Council, and if such nomination be duly seconded and agreed to by resolution of the meeting, then the name of such nominee shall be added as a candidate. It shall also be competent for any Ordinary Member to lodge with the Secretary within seven days after the date of such meeting in the month of June, a nomination in

writing in favour of any other financial Ordinary Member or an Honorary Member of the Society to hold office on the Council as President, a Vice-President, Treasurer, Secretary, Librarian, or Editor, or as a member of the Council. Every such nomination shall be in such form as may be prescribed and shall be signed by the member proposing and another Ordinary or Honorary Member of the Society as seconder. If such nomination shall not be lodged within the time aforesaid, or if it should be ascertained that the person nominated—if an Ordinary Member—is not financial at the date of nomination, such nomination shall be null and void. Any member whose subscription is unpaid for more than two months after the due date in any year shall be deemed to be not financial.

17. If the number of members nominated or proposed for election to any of the offices aforesaid, or as a member of Council, shall not exceed the number of vacancies, then the Chairman of the meeting shall declare the persons so nominated as being duly elected ; but if the number of nominations for any office or as members of Council shall exceed the number of vacancies, then an election shall be held in cases where same may be required and the result ascertained if need be by a preferential ballot. For the purpose of such election a ballot paper containing the names of all persons nominated (except the nominations of such persons as may be disallowed or not included by reason of being not financial members) shall be posted to members entitled to vote on a date being not less than 14 days prior to the date of the Annual General Meeting. It shall be the duty of all members desirous of voting to hand in or cause to be delivered to the Secretaries such ballot papers, duly completed, in accordance with any instructions thereon at or prior to the commencement of the Annual General Meeting. Ballot papers not received at or prior to the commencement of the Annual General Meeting may be rejected by the Chairman. Before proceeding with the examination of the ballot papers the meeting shall appoint not less than two scrutineers, who shall report the result of their scrutiny and examination of the ballot papers to the Chairman of the meeting and the Chairman shall subsequently announce the results to the meeting or at the next ordinary meeting of the Society.

18. All retiring members of Council, including those holding the offices aforesaid, shall be eligible for re-election and each Council so elected as aforesaid shall hold office until their successors be appointed.

19. Any casual vacancy or vacancies arising during any financial year amongst the holders of any office or members of Council may be filled by the Council, and any member or members so appointed shall hold office for the period for which the person in whose place he is appointed would have held same. Any vacancy not filled at any Annual General Meeting shall be deemed to be a casual vacancy.

20. The Council may define the duties of the Secretaries and may add any distinguishing word to the title of one or more of the Secretaries in accordance with the nature of the duties to be performed.

21. The Council shall meet at such times as may be appointed by the President, or in his absence, by one of the Vice-Presidents, or by a Secretary, and due and sufficient notice shall previously be sent to each member of the Council.

22. A quorum for a meeting of Council shall be four members thereof present, and no business shall be transacted at any Council meeting unless such quorum of four or more members is present. If a quorum shall not be present within half-an-hour after the meeting has been summoned, then the meeting may be adjourned to such date, hour, and place as may be decided by the members present.

23. If any member of the Council (including holders of offices) shall fail to attend three consecutive meetings of the Council without satisfactory explanation, or reason, or without leave of absence having been first granted to him, then the position or office of such member may by resolution of the Council be declared vacant, and on passing of such resolution he shall cease to be a member of Council and holder of any office to which he may have been elected.

24. The Council shall present and cause to be read at each Annual General Meeting a report giving a review of the work of the Society during the preceding year, and some details and information with regard to its progress and affairs ; and such report may be printed in the Volume of Proceedings for that year.

25. The Council may from time to time make, alter, and repeal By-laws not inconsistent with these rules and regulations to enable the Council more effectually to carry out the management of the affairs of the Society, and to regulate the conduct of members and assist in the protection of its property, and for such purposes as may be calculated to advance the welfare of the Society.

26. The Council, without limiting its general powers of management and carrying on the business and affairs of the Society, may exercise and do all things necessary, except such as may be required or directed to be exercised by General Meetings, including power to appoint and remove all or any officers, assistants, employees, or others deemed by the Council to be necessary in connection with the work of the Society, and that with or without remuneration and upon the terms and conditions as the Council may think fit, with power to determine any such appointment and a new appointment or appointments from time to time to make. The Council may also delegate all or any of its powers or authorities to any committee or sub-committee from time to time, and may pay all or any expenses or liabilities incurred from time to time and take any steps or proceedings which may be deemed desirable for the purpose of carrying out or securing the fulfilment of any of the objects or purposes of the Society.

PRESIDENT AND VICE-PRESIDENTS.

27. The duties of the President shall be to preside at all meetings of the Society and Council, and regulate all the proceedings therein ; and generally to execute or see to the execution of the Rules and By-laws of the Society. In the case of an equality of votes at any meeting, the President or Vice-President or member presiding shall have a casting vote in addition to a deliberative vote.

28. In the absence of the President from any of the meetings of the Society or Council, his place shall be filled by one of the Vice-Presidents, or, in their absence, by a member of the Council, or, failing such, a Chairman may be elected by the members, being a quorum then present, who shall for the time being have all the authority, privileges, and power of the President.

DUTIES OF OFFICERS.

29. The Secretaries or Honorary Secretaries, from time to time appointed in connection with the Society, shall conduct all the correspondence relative to the objects or work assigned to them respectively, and shall also on instructions from the President or other authorised officer, cause notices of all meetings to be sent out, and be in attendance at all meetings and keep a correct

record of the proceedings of all such meetings, and also a register of all of the members, and issue and receive all notices, ballot papers and communications which may be necessary in connection with elections which may be held at any time or times, and generally perform and carry out such duties as are usually assigned to persons holding such an office, and comply with the directions, requests, or instructions from time to time of the Council.

30. The Treasurer or Honorary Treasurer shall cause to be kept a correct account of all receipts and disbursements, and cause all subscriptions and moneys received for the benefit of the Society to be recorded in the books of account and forthwith paid to the credit of the Society at its bankers. It shall also be the duty of the Treasurer or Honorary Treasurer to pay all accounts passed by the Council. No moneys shall be withdrawn from the bank account except by cheque signed by the Treasurer or Honorary Treasurer and a Secretary or Honorary Secretary or such other person or persons as the Council may authorise. The Treasurer or Honorary Treasurer shall also cause the books of the Society to be regularly posted, and shall bring his books to a balance as on the 30th day of June in each year, or such other date as the Council may from time to time decide.

31. The Treasurer or Honorary Treasurer shall also, prior to the Annual General Meeting of the Society in each year, submit to the Auditor or Auditors of the Society all books and accounts kept by him in connection with the affairs of the Society, made up to the date last mentioned. For the purpose of every such audit being carried out the Society shall, not later than its General Meeting in the month of June in each year, appoint some person or persons to be auditor or auditors, but if any General Meeting shall fail to make such appointment then the Council may appoint an auditor or auditors.

32. It shall be the duty of the auditor or auditors of the Society to submit their report, if available in the first place, to the Council; but failing this, to the Annual General Meeting in each year.

ORDINARY GENERAL MEETINGS.

33. The Ordinary General Meetings of the Society shall take place at 8 p.m. on the second Tuesday in every month during the last ten months, *i.e.*, from March to December inclusive, in every calendar year, unless the Council determines otherwise. Notices of Ordinary General Meetings shall be forwarded to all members. Special meetings of the Society may be called by the Council whenever it may deem such expedient, or on the requisition of ten members in writing and specifying the purpose for which the meeting is required, sent to the Secretaries, who shall thereupon call a meeting within not less than seven days nor more than twenty-eight days. A quorum for an Ordinary General Meeting shall be seven Ordinary Members personally present.

34. The proceedings at the Ordinary General Meetings after the Chair has been taken shall, subject to any variation the meeting may agree to, be as follows:—

(1) Minutes of the proceedings of the previous meeting.
(2) Correspondence.
(3) Communications from Council.
(4) Nomination and election of members when requisite.
(5) Donations to be laid on the table and acknowledged.
(6) Any business of which notice may have been given or agreed by the meeting to be considered, and also any formal or general business to be dealt with.
(7) Lectures, papers, exhibits, and discussions thereon.

35. At the Ordinary General Meetings of the Society nothing relating to the regulations or management, except as regards the election of members, shall be brought forward unless the same shall have been announced in the notice calling the meeting, or be otherwise provided for in these Rules.

ANNUAL GENERAL MEETING.

36. The course of Proceedings after the Chair has been taken shall, subject to any variation the meeting may agree to, be as follows:

(1) Minutes of the previous Annual Meeting.

(2) Reading of nominations of candidates for Council, appointment of scrutineers, election, and opening of ballot.

(3) Presentation and discussion of the Council's Annual Report.

(4) Presentation and discussion of the Balance Sheet, Statement of Accounts, and Auditors' Report.

(5) Report of the scrutineers on the result of the ballot and declaration or announcement by Chairman.

(6) President's Address.

(7) Any business of which notice may have been given or agreed by the meeting to be considered.

37. At the Annual or any Special General Meeting seven members, who shall be Ordinary or Honorary Members of the Society, personally present, shall constitute a quorum.

SCIENTIFIC CONTRIBUTIONS TO THE SOCIETY.

38. Every paper intended to be read before the Society or to be published in the Society's Journal must be sent to the Secretaries at least seven days before the date of the next ensuing Council meeting, to be laid before the Council. It will be the duty of the Council to decide whether such contribution shall be accepted, and if so, whether it shall be read in full, in abstract, or taken as read. All papers accepted for publication must be read or otherwise communicated at an ordinary meeting prior to publication.

39. A Publications Committee, appointed by the Council, shall recommend to the Council whether a paper presented to the Society shall be published in the Society's Journal. The Publications Committee may obtain an opinion from any person it may select on the suitability of any paper for publication.

40. Publication in the Society's Journal shall only be available to (*a*) Ordinary Members, (*b*) Honorary Members, (*c*) Non-members resident outside Western Australia, who must communicate the paper through an Ordinary or Honorary Member. No paper shall be accepted from a Non-member resident in Western Australia.

41. The original copy of every paper accepted for publication by the Society, with its illustrations, shall become the property of the Society, unless stipulation is made to the contrary, and authors shall not be at liberty to publish their communicated papers elsewhere prior to their appearance in the publications of the Society unless permission for so doing is given by the Society, or unless the Society fails to publish the paper in the Journal of the year in which it is read or otherwise communicated, or of the succeeding year.

ROYAL SOCIETY'S MEDAL.

42. A Medal, together with the sum of fifteen guineas, shall be awarded by the Council at such times or periods as the Council may from time to time decide for distinguished work in science connected with Western Australia. The method of making an award shall be as follows :—

(*a*) Awards shall be made by the Council only on a recommendation by a Medal Committee, and such recommendation shall require to be approved by not less than three-fourths of the members present at the Council meeting.

(*b*) The Medal Committee shall consist of five members of Council and shall be representative of various branches of science.

(*c*) Any recommendation by the Medal Committee for the award of the Medal must have the approval of at least four of the five members of the Committee, and shall be accompanied by a statement setting forth the facts on which the recommendation is based.

(*d*) The Council shall from time to time, subject to funds being available, appoint a Medal Committee—(i.) in the year 1936 and in the fourth year after any year in which an award has been made ; (ii.) in each alternate year thereafter until an award is made, if any award has not been made as a result of the appointment of a Committee under the previous subsection ; and (iii.) at such times as the Council may consider it advisable to consider the question of an award to a particular individual, but no Committee shall be appointed under this subsection unless such action is approved by not less than three-fourths of the persons present at a Council meeting of which due notice of such proposed action has been given to each member.

(*e*) Any Medal Committee which is appointed under these Rules shall report to the Council before the end of the Society's then current financial year, and shall then lapse.

FORMATION OF SECTIONS.

43. Sections may be formed for the purpose of any particular branch of science. Any financial member of the Society may be enrolled as a member of one or more sections without being required to pay any further subscription. Each section shall appoint a Chairman and Secretary, who shall be approved by the Council. Notice of sectional meetings shall be made on the usual notice card to members. Sections shall not incur expenditure without first obtaining the approval of the Council. Any communication to a section may be presented subsequently at a general meeting of the Society.

JOURNAL.

44. (*a*) The Society shall publish a Journal at least once a year in which papers communicated to the Society during or before that year may be printed. The Journal and contributions shall be printed in such form as may be decided by the Council.

(*b*) The published price of the Journal shall be fixed by the Council from time to time.

(c) Reprints of papers are available to authors, provided that the required number of such reprints be stated before the paper is read or otherwise communicated to the Society. The number of covered reprints of any paper which shall be supplied free of charge to the author, or divided between the authors of the paper, and the rate at which additional reprints may be obtained by authors, shall be determined from time to time by the Council.

COMMON SEAL.

45. The Common Seal of the Society shall be in the custody of the President or one of the Vice-Presidents for the time being, and the President or any one Vice-President shall respectively be authorised to use the same and when required to be affixed to any deed, document, or writing, shall be so affixed by either the President or one of the Vice-Presidents and signed by him and countersigned by a Secretary of the Society.

INTERPRETATION OF RULES.

46. Should any doubt arise as to the meaning or application of these rules or regulations, the Council shall have power to decide the same and such decision shall be final.

WINDING UP OF SOCIETY.

47. The Society may be wound up by a resolution to be passed by a four-fifths majority of the Ordinary Members of the Society present at a meeting summoned for such purpose, whereof at least seven days notice shall be given. If a resolution to wind up be passed, all property and assets of the Society shall be disposed of or applied in such manner as may be decided at such meeting.

ALTERATION OF RULES.

48. The Constitution objects and these rules and regulations, or any of them, may be amended, altered, enlarged or repealed from time to time by a resolution passed by a two-thirds majority of the Ordinary Members present at any Ordinary or Annual or Special General Meeting of the Society, whereof at least fourteen days' notice shall be given, and in which notice the proposed amendments or alterations shall be specified.

ABSTRACT OF PROCEEDINGS, 1937-1938.

13TH JULY, 1937—

Annual General Meeting held at the Museum. Presidential Address: "A Contribution to our Knowledge of the Pre-cambrian Succession in some Parts of Western Australia."

10TH AUGUST, 1937—

Papers—"Tertiary Tholeiite Magma in Western Australia," Dr. A. B. Edwards, communicated by Dr. Dorothy Carroll.

"The Geology and Physiography of the Lower Chittering Area," K. R. Miles.

"Western Australian Mydoidae," K. R. Norris.

"The Suspensor and Embryo of Actinostrobus," Miss A. M. Baird.

7TH SEPTEMBER, 1937—

Paper—"Palaemonetes Australis Dakin in South-Western Australia," D. L. Serventy, communicated by L. Glauert.

Lecture—"Time and its Measurement," Mr. J. Shearer.

12TH OCTOBER, 1937—

Papers—"Western Australian Forms of the Giant Petrel," L. Glauert.

"The Genus Corysanthes (Orchidaceae) in Australia and New Zealand," Rev. H. M. R. Rupp, described by Lieut. Colonel Goadby.

Lecture—"Some Economic Sidelights of Plant Pathology," Mr. H. A. J. Pittman.

9TH NOVEMBER, 1937—

Paper—"Essential Oils of Australian Eucalypts," Part V., G. E. Marshall and E. M. Watson.

Lecture—"Copper Deficiency in Sheep in Western Australia with Special Reference to the Gingin District," joint lecture by Dr. H. W. Bennetts and Mr. F. E. Chapman.

14TH DECEMBER, 1937—

Paper—"Upper Eocene Foraminifera from a Bore in King's Park, Perth," Mr. W. J. Parr, communicated by Professor E. deC. Clarke.

Rottnest Island—Reports were given by the Leaders of Parties during the Excursion to Rottnest Island on 20th and 21st November.

8TH MARCH, 1938—

Paper—"The Ascorbic Acid (Vitamin C) Content of some Western Australian Fruits," Mr. H. E. Hill.

Address—"The Royal Society Library," Mr. L. Glauert.

Presentation—A presentation was made to Mr. Glauert prior to his tour of America and the Continent.

12TH APRIL, 1938—

Paper—"Contributions to the Mineralogy of Western Australia," Series XI., Dr. E. S. Simpson.

Address—Dr. Petrie, with him Mr. D. C. Fox, spoke on the activities of the Ethnographic Institute of Frankfurt-on-Maine and proposed studies in the Kimberleys.

Exhibit—Motion picture film illustrating some of the customs of natives of the Worrora and Gnaringin tribes—Mr. A. O. Neville.

10TH MAY, 1938—

Lectures—"Food and the Chemist," Dr. L. W. Samuel.
"Polyploidy and Vitamin Content of Plants," Mr. C. B. Palmer.

14TH JUNE, 1938—

Lecture—"The Summer Feeding of Sheep in Western Australia," Mr. A. B. Beck.

EXHIBIT.

14TH DECEMBER, 1937—

Mr. L. Glauert exhibited a lower jaw of the False Killer Whale *Pseudorca crassidens,* obtained from the Drysdale River Mission region. This is the first occasion on which the species has been recorded in Western Australia.

JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

VOLUME XXIV.

1.—TERTIARY THOLEIITE MAGMA IN WESTERN AUSTRALIA.

By A. B. EDWARDS, Ph.D.

Communicated by Dorothy Carroll, Ph.D.

Read 10th August, 1937; Published 28th January, 1938.

INDEX OF CONTENTS.

INTRODUCTION.

Subsequent to a description of the tholeiitic basalts of Cape Gosselin (1[illegible]) Professor E. de C. Clarke and Dr. Dorothy Carroll kindly placed at my disposal specimens of Tertiary basalts from all the other known localities in the south-west of Western Australia, viz. from Bunbury [1686], from Gelorup, about 5 miles south of Bunbury [16263], from the Capel River [1[illegible]195], and from the mouth of the Donnelly River [4342]. The localities are shown in Figure 1. These are all varieties of theoleiite more or less similar to the Cape Gosselin tholeiites. A further specimen [4496], said to come from Bridgetown, but of doubtful locality (probably Darradup) is also a typical tholeiite. Chemical analyses of the Bunbury and Donnelly River tholeiites were made in the Geology Department, University of Melbourne, by permission of Professor Skeats. The analyses and the mineralogical compositions of these rocks make it clear that they are fairly typical plateau basalts.

THE TERM "THOLEIITE."

It is well at this stage to state what is meant by the term "tholeiite." As employed by Rosenbusch (19, p. 427) and by Holmes (15, p. 225) tholeiite indicates a basaltic rock showing intersertal texture, and free from olivine,

consisting essentially of calcic plagioclase, pyroxene and iron-ores, the interstices being occupied by a mesostasis of glass, globulitic glass, or devitrification products. Olivine-bearing types were distinguished as olivine-tholeiites. Tyrrell (21, p. 240) expanded the term to include similar rocks which carry phenocrysts of plagioclase approaching anorthite in composition; and Holmes and Harwood (16, p. 9) adopted this wider sense when classifying the various types of tholeiite dykes in the north of England.

More recently, however, Kennedy (17, 18) has suggested that the significance of the tholeiites lies in their distinctive chemical and mineralogical characteristics, and in their petrographic association, rather than in their intersertal texture. In the light of his work a *tholeiite* may be defined as a basaltic rock containing little or no olivine, basic plagioclase, lime-poor pyroxenes (pigeonites) and iron ores, in a mesostasis of glass; and giving rise to an acid quartzo-felspathic residuum. They are thus quite distinct from the *olivine-basalts* which contain abundant olivine, basic plagioclase, and lime-rich pyroxenes (diopsidic augites), and give rise to an alkaline, quartz-free residuum. The emphasis of the distinction is thus placed on the types of pyroxene which characterise the rocks, and the character of their subsequent differentiates. These two widespread types of basalt are regarded by Kennedy as corresponding to two types of primary basalt magma (18) whose chemical composition are as follows:—

	Olivine-basalt Magma type.	Tholeiite Magma type.
SiO_2	45	50
Al_2O_3	15	13
Fe_2O_3,FeO	13	13
MgO	8	5
CaO	9	10
Na_2O	2·5	2·8
K_2O	0·5	1·2

The acid differentiates of the olivine-basalts are trachyandesites, trachytes and phonolites; those of the tholeiites are quartz-dolerites, andesites and rhyolites.

This is to make the rock type "tholeiite" practically synonymous with that of "plateau basalt," introduced by Washington (24). The textural significance of the term tholeiite is conveyed with equal adequacy by the terms "mero-crystalline" and "mesostasis." If it is to be retained in this, its original, sense, it should be used only as an adjective, "tholeiitic," and not as a rock name, because such a texture is dependent on the local rate of cooling, so that a single flow commonly shows at one place basaltic (intergranular, doleritic, or ophitic) texture, and at another tholeiitic texture. Thus the Whin Sill, while normally a quartz-dolerite, is marginally tholeiitic. Moreover, the indiscriminate use of the name tholeiite in connection with olivine-basalts (cone-basalts of Washington (24)), and plateau basalts, is liable to introduce a false sense of similarity.

If, on the other hand, as Kennedy indicates, the rocks originally termed tholeiites because of their intersertal texture, also possess a characteristic chemical and mineralogical composition, and a distinctive petrographic association, it seems desirable to broaden the definition to include these features, thus constituting tholeiites as a definite type of plateau basalt.

The Western Australian rocks to be described qualify for the use of the term, whichever meaning is attached to it.

THE WESTERN AUSTRALIAN THOLEIITES.

1. *The Bunbury Tholeiite.*

The outcrop of tholeiite at Bunbury, about 90 miles south of Perth, has been mapped and described by Saint Smith (20, p. 15). His map was based on an earlier one by Gibb Maitland (Ann. Progress Report, Geol. Survey W. Aust., 1897). Much additional information has been accumulated by the Public Works Department in Perth, and this was kindly placed at Professor Clarke's disposal by Mr. Stevenson Young, of the Harbours and Rivers Department, and Mr. Hutchinson of the Water Supply Department. The accompanying geological map (Fig. 2) and sections (Fig. 3) were compiled by Dr. Carroll from bore records and data obtained from large scale maps of the Public Works Department, W.A.

The tholeiite outcrops at sea level as a nearly horizontal flow, stretching southwards along the western coast for about a mile from the Breakwater at Point Casuarina. The surface of the lava rises slightly towards the south, and the bore records indicate that the flow dips towards the east (Fig. 3). The outcrop is in part a wave-cut platform, in which the sea has eroded channels, but there are more elevated parts which appear to be remains of old sea cliffs, and are now covered by sand dunes. Along the coast the tholeiite shows strong vertical columnar jointing, the columns being rudely pentagonal in cross section and averaging about 15 inches in diameter. Some portions weather much more readily than others, suggesting a possible variation in composition or texture. The Breakwater itself is built on the reef formed by the western edge of the tholeiite flow, which extends beneath Koombana Bay, at a depth of 20-35 feet below low-water mark. It is covered by sands and clays, and has an irregular surface, since probing (records) revealed "pockets" containing clay and plant remains.

The flow continues under the township of Bunbury, beneath a cover of sands and clays, as far east as the railway line, where, although there is no surface feature to indicate a change, the bore records show several hundreds of feet of sediments (Section CD, Fig. 3). The most easterly bore again strikes the tholeiite at 46 feet below the surface (Figs. 2, 3), as do those on the northern shore of the Leschenault Estuary. The geological section suggests that there is here an old in-filled valley which had walls of lava, indicating either intense local erosion of the flow, or trough faulting, subsequent to its extrusion. A third possibility is that there is more than one lava flow present, but this does not explain the continuity along the section AB (Fig. 3), or the steep edges of the lava indicated by the bores along the Section CD (Fig. 3). Recent elevation has not been sufficient for erosion to expose the greater part of the tholeiite.

The variable thickness of the flow, from 50 to 97 feet, and its occurrence at different heights above sea-level suggest that it was extruded on an old land surface. In places it overlies a red clay, below which are water-bearing sands and gravels.

At Gelorup tholeiite outcrops at 25-30 feet above sea-level, and at Capel (not shown in Fig. 3) a similar lava outcrops at 52 feet above sea-level, indicating that the pre-basaltic land surface was irregular.

The flow is of Tertiary age, and was regarded by the late Professor Edgeworth David as Upper Pliocene (8, p. 87). In some localities it is overlain by the Coastal Limestone Series, which is of Late Tertiary or Recent age. It probably extends to the east and south of Bunbury, but this could be proved only by boring.

The Bunbury tholeiite is a handsome rock, consisting of abundant large columnar phenocrysts of plagioclase set in a dense blackish groundmass. It breaks with an uneven fracture, and is an excellent roadmetal, for which purpose it is quarried. In thin section the large felspar phenocrysts, which may be as large as 10 mm. by 3 mm., are found to consist of a broadly twinned bytownite (Ab_{25}), with a maximum extinction angle in the symmetrical zone, perpendicular to (001) (010), of 38°-39°, following Goransen's data (14). (Note:—The plagioclase phenocrysts in the Cape Gosselin tholeiites (10) given as Ab_{35}, using Idding's diagram (Rock Minerals, p. 228), are also truly bytownites of Ab_{25}.) Some show zoning, the peripheral zones being somewhat more sodic (Ab_{45}): and frequently they are glomero-porphyritic. The plagioclase phenocrysts are set in a mero-crystalline, intergranular groundmass, consisting of plagioclase laths, granular pyroxenes, and a variety of glasses—black, green, and yellow. The plagioclase is labradorite about Ab_{45}: but the individual pyroxenes are too small for their composition to be determined by the optical methods available. The yellow and green glasses grade in colour into one another, and are fibrous from devitrification. They probably differ only in the state of oxidation of their iron content. The black glass is seen, under high magnification, to consist of similar material which contains innumerable globulites and skeletal crystals of iron ore, and represents glass in which the iron oxides had concentrated preparatory to crystallizing out. Small patches of chloritic material, coarser in grain than the groundmass, suggest the previous existence of small microphenocrysts of a ferromagnesian mineral—augite, or possibly olivine.

An analysis of this rock is given in Table I., and is discussed in a subsequent section.

2. *Gelorup Tholeiite.*

A similar basalt [16263] occurs near Gelorup, about 5 miles south of Bunbury on the Capel road. The outcrop, which has been quarried for road metal, is about a mile east of the road (Fig. 2). It is surrounded by thick timber, and to the west there are high sand hills which were at one time sand dunes. The line of high ground runs for some distance north and south, suggesting that the outcrop is only part of a more extensive lava flow.

It is dark grey, crystalline rock, studded with irregular mega-phenocrysts of plagioclase, as large as 0.5 cm. in diameter. Under the microscope it is seen to be a tholeiite, with phenocrysts of basic plagioclase (Ab_{25}) set in a groundmass of plagioclase laths, (Ab_{40-45}), and pyroxene, with a mesostasis of black glass, containing innumerable minute skeletal crystals of iron ore. Patches of green, brown, and yellow-brown glassy material occur throughout the rock, filling small vesicles, and sometimes surrounded by minute columnar growths of pyroxene. The plagioclase phenocrysts show broad lamellar twinning, and are sometimes zoned. Frequently they are segregated into clots along with granular crystals of pyroxene.

Two varieties of pyroxene are present. One is a pigeonite ($2V = 0°-5°$) and optically positive, with relatively low birefringence. The other is a brightly polarizing variety, biaxial, with a fairly large 2V, a birefringence about 0.03, and a relatively high refractive index. It somewhat resembles olivine in appearance, but has a good cleavage, and is probably diopsidic.

3. *Capel River Tholeiite.*

Specimen [16195] is from an outcrop of basalt in the bed of the Capel River, about six miles east of the township of Capel. It is a dark grey, slightly vesicular rock, studded with yellowish phenocrysts of glassy plagioclase, often in small clots.

In thin section it is a typical tholeiite, closely comparable with those from Bunbury and Gelorup. The plagioclase phenocrysts show broad lamellar twinning and strong zoning. The cores of the crystals show a maximum symmetrical extinction of about 38°, corresponding to a composition of Ab_{25}. The outer zones approach basic andesine in composition. They are set in a merocrystalline groundmass of plagioclase laths (Ab_{45}), intergranular to subophitic pyroxene, and a mesostasis of globulitic iron-rich glass. Much of the pyroxene is almost uniaxial pigeonite, with 2V between 0°–5°, with a positive sign. The optic axial angle appears somewhat higher in some instances (about 45°), indicating that there are two types of pyroxene present, presumably a magnesia-rich pigeonite, and a more lime-rich pigeonite. The glassy mesostasis consists of colourless glass crowded with globulites and skeletal crystals of iron ore. Patches of green and orange-yellow glassy material occur throughout the rock, frequently lining small vesicles.

4. *The Donnolly River Tholeiite.*

Outcrops of tholeiite occur at the mouth of the Donnelly River, in the extreme south-west of Western Australia, and a little further inland, three miles north of Silver Mount and one mile south of the junction of Fly Creek with the Donnelly River. The outcrops are shown on H. P. Woodward's map of this part of Western Australia (25).

Gibb Maitland (11, pp. 13-15) records the presence of basalt, at depth, along the Warren River, about 13 miles to the west of the Donnelly River. According to the bore records there are two flows of basalt, 20 to 40 feet thick, intercalated with sands and lignites, and overlying coral limestone, and a fossiliferous sandstone containing saurian remains. Woodward, however, casts doubt on the reliability of the bore records (24), because only an incomplete suite of specimens of the cores were submitted to the Geological Survey, and these did not include any basalts.

The Donnelly River tholeiite resembles that from Bunbury. It is a dark greyish, finely crystalline rock, studded with tabular phenocrysts of glassy plagioclase, which may be as large as 10 mm. by 5 mm., and are frequently glomero-porphyritic. These show broad lamellar twinning, and sometimes zoning. The cores consist of bytownite (Ab_{25}), while the outer zones are more sodic (Ab_{45} about). The groundmass in which these phenocrysts are set consists of laths of plagioclase (Ab_{45}), granular augite, laths of ilmenite, rare apatite rods, and a little devitrified green glass. The pyroxene crystals are too small to determine their composition optically by the means available. The rock is rather more crystalline than the Bunbury tholeiite, and is somewhat similar to the doleritic tholeiites of Cape Gosselin (10).

The outcrop north of Silver Mount is rather more glassy, and is finer grained: and in addition to the plagioclase phenocrysts, contains rare phenocrysts of augite (25).

An analysis of the Donnelly River tholeiite is given in Table 1, and is discussed in a subsequent section.

5. *The Darradup Tholeiite.*

A further outcrop of tholeiite occurs at Darradup, on the Blackwood River, about 30 miles north of Cape Gosselin. This is probably the locality of specimen No. 1496, labelled Bridgetown (which is some miles to the east, in gneiss country). Farquharson (25, p. 52) described the Darradup rock as a porphyritic doleritic basalt, with phenocrysts of basic plagioclase, set in

a doleritic or subophitic groundmass of plagioclase, augite, and black areas containing much iron, with occasional, almost isotropic, green chloritic patches pseudomorphous after a ferromagnesian mineral.

This description fits Specimen No. 4496, which consists of phenocrysts of bytownite (Ab_{25}) set in a coarse merocrystalline to sub-ophitic groundmass of plagioclase laths (Ab_{65}), ophitically intergrown with a pigeonitic pyroxene ($2V = 40°$), and with abundant intersertal dark glass, the dark appearance of which is due to the presence of innumerable globules and skeletal crystals of iron oxide. The glassy matrix consists of devitrified yellow or green glass, and this occurs as clear patches. Occasional small green chloritic areas are obviously pseudomorphous after a ferromagnesian mineral, which may have been augite or olivine.

6. *The Cape Gosselin Tholeiites.*

These have been described previously (10). They resemble the various tholeiites just described except in their lack of megaphenocrysts of bytownite.

CHEMICAL ANALYSES.

In the following table the two new analyses are given together with that of the Cape Gosselin tholeiite. In addition, analyses of typical Salen, Brunton, and Talaidh types of tholeiite are appended for comparison.

TABLE I.

	1.	2.	3.	S.	B.	T.
SiO_2	49·46	50·57	51·14	50·41	50·07	51·28
Al_2O_3	14·74	15·11	14·56	15·14	14·53	14·83
Fe_2O_3	2·45	3·65	4·05	2·71	1·76	2·49
FeO	9·10	8·80	7·04	7·95	8·26	5·89
MgO	6·30	5·55	6·25	6·57	6·77	7·45
CaO	12·01	10·64	10·15	11·30	11·50	11·59
Na_2O	2·65	2·29	3·96	2·29	1·93	1·93
K_2O	0·55	0·57	0·58	0·82	0·85	0·66
H_2O+	0·13	0·25	0·54	1·01	0·82	0·91
H_2O-	1·40	1·42	1·35	0·72	0·52	1·41
CO_2	tr.	nil	0·05	0·07	1·61	0·45
TiO_2	1·48	1·37	0·01	1·30	1·14	0·87
P_2O_5	0·03	0·07	0·02	0·15	0·16	0·14
MnO	0·17	0·26	0·16	0·17	0·19	0·20
Cl	n.d.	n.d.	*Nil*	n.d.	tr.	n.d.
S	n.d.	n.d.	*Nil*	0·06	0·08	0·06
BaO	n.d.	n.d.	*Nil*	0·03	0·04	0·01
	100·18	100·55	99·86	100·80*	100·33†	100·24‡

* Etc. 0·05 † Etc. 0·10 ‡ Etc. 0·07

1. Tholeiite, Bunbury (No. 1686). Analyst, A. B. Edwards.

2. Tholeiite, Mouth of the Donnelly River (No. 4342). Analyst, A. B. Edwards.

3. Tholeiite, Cape Gosselin (No. 10353). Analyst, A. B. Edwards (10, p. 20.)

S. Olivine-tholeiite (Salen type), Kielderhead, Northumberland. Analyst, H. F. Harwood (16, p. 16).

B. Tholeiite (Brunton type), Bingfield Dyke, Redhouse Burn, Northumberland. Analyst, H. F. Harwood (16, p. 23).

T. Tholeiite (Talaidh type), Kielder Viaduct Dyke, Kielder Burn, Northumberland. Analyst, H. F. Harwood (16, p. 28).

Examination of Holmes and Harwood's study of the tholeiite dykes of the north of England (16) makes it clear that the West Australian tholeiites have close affinities with the Salen, Brunton, and Talaidh (pronounced Tala) type of English tholeiites, both chemically and mineralogically. The presence of phenocrysts and clots of basic plagioclase, bytownite in the West Australian rocks, is parallel to the common presence of bytownite-anorthite phenocrysts and clots in the English types. The occasional olivine in the Cape Gosselin tholeiites, and the presence in the Bunbury and Darradup rocks of pseudomorphs, possibly after subordinate olivine, indicate an affinity with the Salen type of tholeiite. The micro-textures of the Australian tholeiites, moreover, are comparable with those of the Salen and Brunton types. The "sheaves and fan-shaped cervicorn groups of slender augite," characteristic of the Talaidh type, have not been observed.

In certain respects, however, the West Australian tholeiites differ from the English types. They are extremely deficient in phosphorus, and rather richer in total iron oxides and soda.

In Table II. the average of the three West Australian tholeiites is compared with Plateau Basalts (24) from several parts of the world.

TABLE II.

	1	2	3	4	5
SiO_2	50·39	50·61	47·60	48·79	50
Al_2O_3	14·80	13·58	12·76	11·96	13
Fe_2O_3	3·38	3·19	2·49	2·51	13
FeO	8·31	9·92	10·83	12·10	
MgO	6·03	5·46	5·79	5·60	5
CaO	10·93	9·45	10·71	10·15	10
Na_2O	2·93	2·60	2·15	2·40	2·8
K_2O	0·57	0·72	0·56	0·70	1·2
TiO_2	0·96	1·91	...	4·17	...
P_2O_5	0·04	0·39	...	0·37	...
MnO	0·20	0·16	...	0·21	...

1. Tholeiite of Western Australia (3 analyses).
2. Deccan Traps (11 analyses).
3. Faroe basalts (2 analyses).
4. Iceland basalt (1 analysis).
5. Non-porphyritic Central Magma-type of Mull.

It will be seen that the West Australian rocks, though similar, contain less phosphorus and titania, and rather less iron than the typical plateau basalts, and rather more alumina, lime, and magnesia.

Chemically, therefore, they are intermediate between these two closely related types—tholeiite and Plateau Basalt.

A SUGGESTED CLASSIFICATION.

Despite the close mineralogical and chemical similarity of the West Australian tholeiites so far described, they may be divided into two main groups:—

(1) Tholeiites of the *Bunbury type*, with megascopic phenocrysts of bytownite, and

(2) Tholeiites of the *Gosselin type*, in which microphenocrysts of bytownite are present, but megaphenocrysts are characteristically absent.

Further subdivision on the basis of the abundance or paucity of the glassy mesostasis does not seem to be warranted, since this feature is so closely related to local variations in the rate of cooling after extrusion within a single lava.

Using this classification, the Bunbury, Gelorup, Capel River, and Donnelly River tholeiites are of the Bunbury type, while the Cape Gosselin and Darradup rocks are of the Gosselin type.

THE EXTENT OF THE THOLEIITE MAGMA.

It is clear that the extreme S.W. part of Western Australia was intruded during Tertiary times by an extensive tholeiite magma. The volume and extent of the extrusions arising from this magma cannot be gauged from the meagre existing outcrops. Some of these are merely residuals of larger flows: others are uncovered portions of otherwise hidden flows of unknown size. Still other lavas are completely buried, and can only be discovered by deep boring. Further search wherever the underlying sedimentary series is exposed should reveal additional necks, dykes, or pipes, by which lava flows, now eroded, reached the surface. Gibb Maitland (13, p. 42) refers to the existence of such dykes.

It is possible, as he has suggested (13, p. 42), that the tholeiite magma was not confined to the S.W. corner of the State, but was much more widespread (Fig. 4). Examination of West Australian publications has revealed a number of recorded occurrences of lavas, dykes, and sills of tholeiitic character or affinity in various districts. Only rocks which were quite fresh and unmetamorphosed, and showed intrusive relations to all but Tertiary rocks, were considered. Tholeiitic types complying with these specifications have been recorded from Norseman (3) [lat. 32° 10′ S.: long. 121° 48′ E.], East Murchison (6) [lat. 26° 20′ S.: long. 115° 0′ E.], Yilgarn (2) [lat. 30° 40′ S.: long. 119° 0′ E.], Meekatharra (7) [lat. 26° 39′ S.: long. 118° 32′ E.], Yalgoo (4) [lat. 28° 23′ S.: long. 116° 40′ E.], and in the region between Laverton and the South Australian border (22) [lat. 28° 40′ S.: long. 122° 29′ E.], but their most extensive development is in the Lofty Ranges, and the drainage basin of the Ashburton River [lat. 22° 0′ S.: long. 115° 0′ E.], and in the Hamersley-Ophthalmia Plateau (23) [lat. 22° 0′ S.: long. 117° 0′ E.]. The rocks of these tholeiite suites are norites, tholeiites, and quartz-dolerites, frequently containing micro-pegmatite, and a little hornblende.

The age relations of these rocks are generally indeterminate. Those in the Meekatharra district intrude the (?) Tertiary Oakover limestones (7); between Laverton and the South Australian border they are overlain by the Wilkinson Range series, which are presumed to be either late Mesozoic or Tertiary (22). Elsewhere their age is indefinite.

Gibb Maitland suggests (13, p.43) that the lavas "may be of Middle or Late Tertiary age, and belong to the same period as the volcanic rocks occurring in South Australia and Victoria."

The tholeiites of S.W. Western Australia, and the olivine-basalts of Victoria are comparable in other directions. Both have developed in areas remote in space and time from orogenic periods: both have intruded a sedimentary and granitic crust: and both are situated near the continental margin.

Why, then, are they so different? In Victoria the basaltic magma gave rise to a typical olivine-basalt-trachyte suite (9): in Western Australia it gave rise to tholeiites. Since the generally comparable situations of these two basalt provinces preclude the possibility of such differences arising from assimilation, it seems necessary to postulate either that they resulted by very different types of differentiation (1), or that they were derived from initially different types of primary magma—olivine-basalt magma in the one instance, and tholeiite magma in the other: and that they therefore provide a local confirmation of the generalised hypothesis of W. Q. Kennedy (18).

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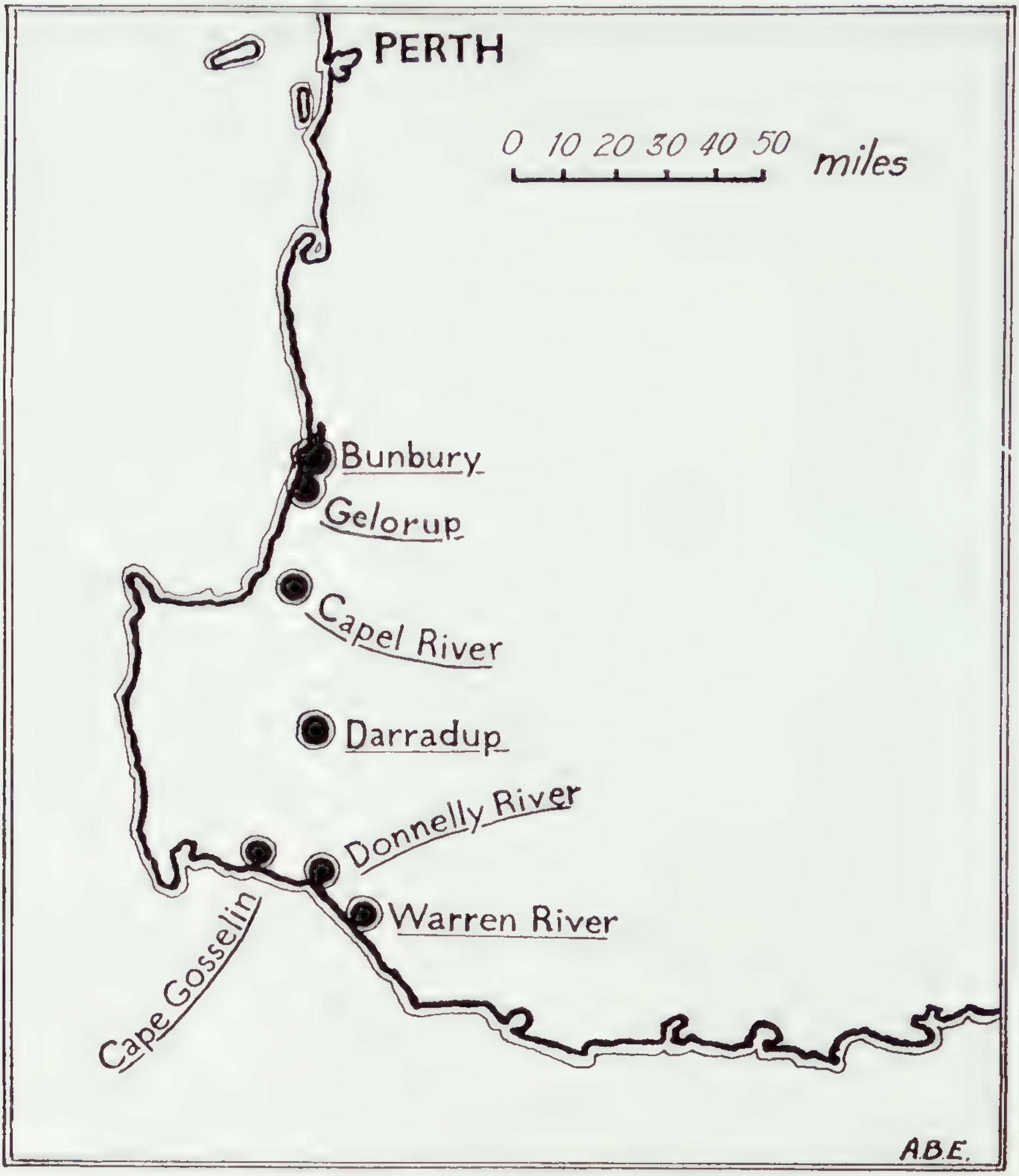

Fig. 1.—Locality Sketch Map.

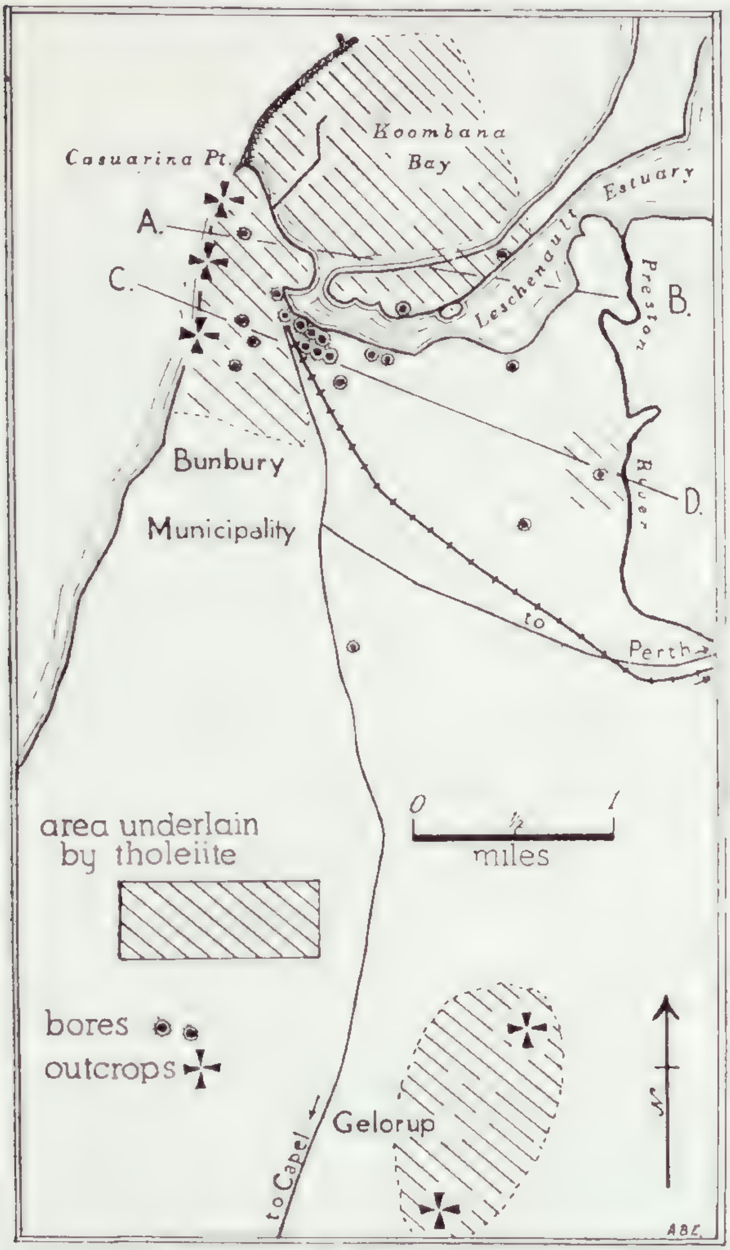

Fig. 2.—Sketch map of the Bunbury-Gelorup District, showing the known extent of tholeiite lavas and position of bore holes. (By the kindness of Dr. D. Carroll.)

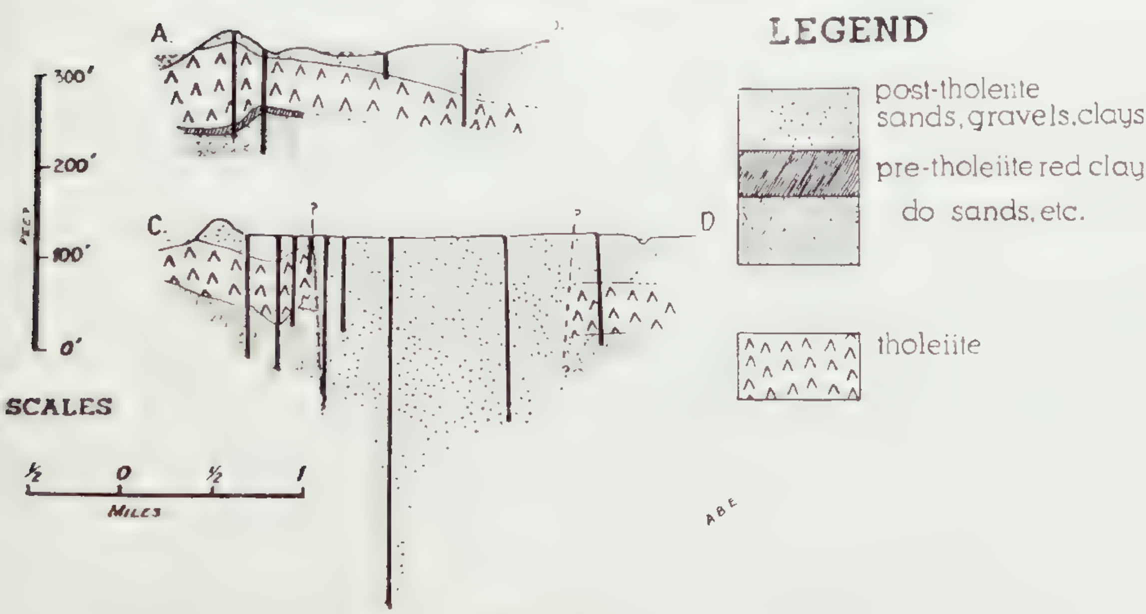

Fig. 3.

Geological sections along the lines A.B. and C.D. in Fig 2. Based upon boring records. (By the kindness of Dr. D. Carroll.)

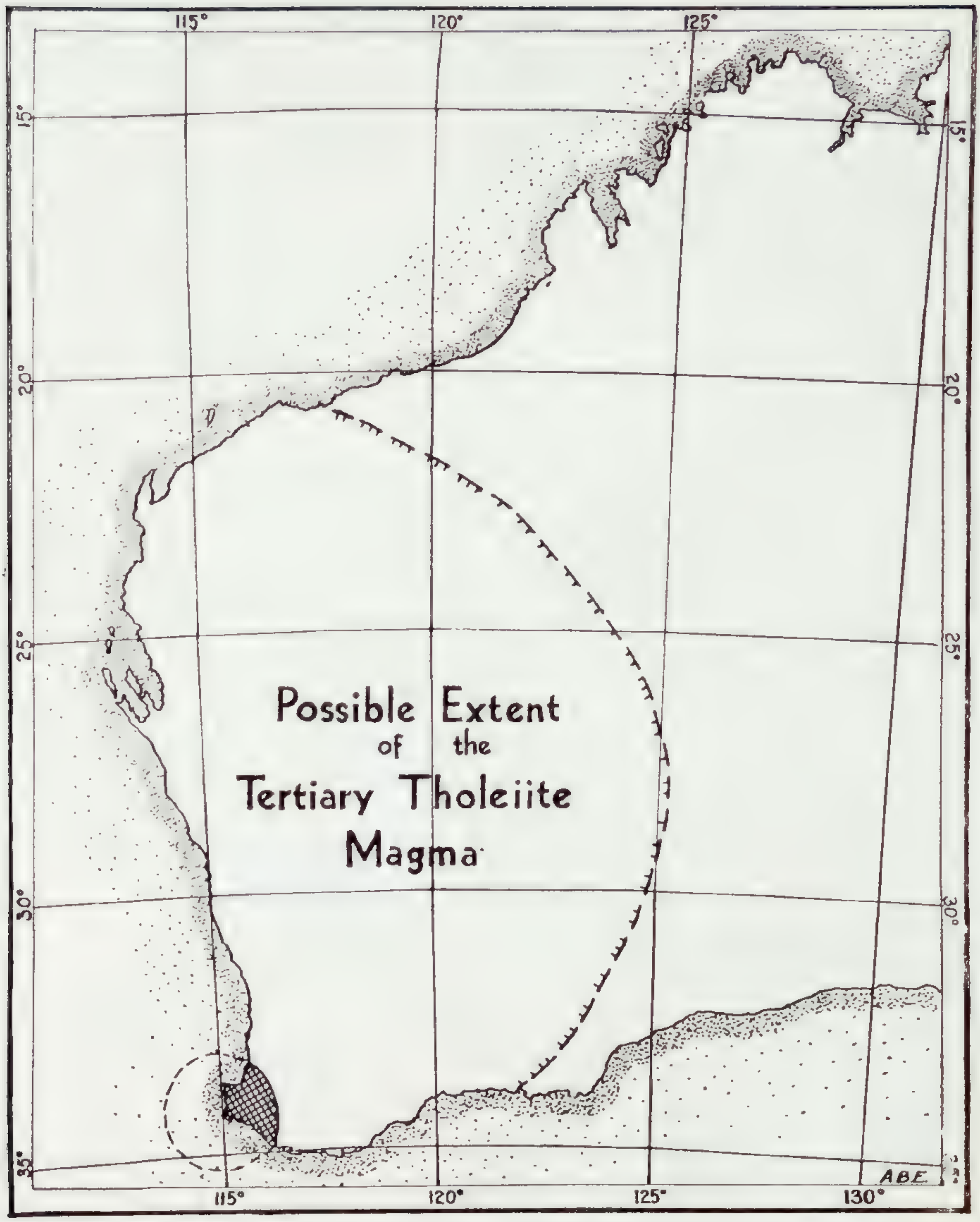

Fig 4.—Map showing the probable extent (shaded) of the Tertiary Tholeiite Magma in Western Australia, and its possible extent.

2.—THE GEOLOGY AND PHYSIOGRAPHY OF THE LOWER CHITTERING AREA.

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CONTENTS.

1.—INTRODUCTION

When travelling northwards along the main Perth-Gingin road at about twelve miles from Perth one sees, rearing up steeply a few miles to the east, the sharp straight line of the Darling Fault Scarp which forms the western margin of the Darling Peneplain (Jutson, 1913). As one approaches Bullsbrook, some 30 miles north-east of Perth, one may notice, however, that the topography of the country is changing, nearly all trace of the typical clean-cut, steeply sloping scarp face becoming lost in broken spurs and numerous deeply dissected, flat-topped hills.

In this country at about 37 miles by road north-north-east of Perth is situated the Lower Chittering Area which covers about twelve and a half square miles, its southern boundary being about half a mile north of the junction of the Chittering Brook with the Swan, or (as it is here called) the Avon River.

The area under discussion is very sparsely populated, in the south there being one or two farms devoted to mixed farming. Here some slopes are being cultivated for wheatgrowing and for sheep pastures. In the northern part of the area there are several small orchards growing citrus fruits. Farther north of the area, the valley of the Chittering is more thickly settled and carries numerous orchards famous for their oranges.

To the south and nearer Perth the country, some areas of which have been mapped in detail (Clarke & Williams, 1936; Fletcher & Hobson, 1931), consists of granitic rock invaded by a younger granite and by still later basic dykes, whereas this area contains portions of a complex system of metamorphosed rocks probably of Yilgarn age, for which I propose the name Chittering Series. This series is probably older than, or at least a lower portion of, the metamorphic rocks of the Jimperding Area—known as the Jimperding Series, which have recently been mapped (Prider, 1932-4).

As is pointed out later, the Chittering and Jimperding Series both form part of a belt of complex metamorphic rocks which extend northwards past Moora, and south-eastwards from Jimperding to Clackline and York. Apart from the detailed work of Prider (cited above) on these metamorphics, Dr. E. S. Simpson has written a number of papers (1926, 1928, 1930, 1932, 1936) dealing with the occurrence of some of the interesting rocks and minerals to be found in this metamorphic belt, while Mr. J. E. Wells has been responsible for the discovery in the field of many of these minerals.

Detailed geological mapping of the area was commenced in 1935 when portion of the southern half of the area was mapped by a party of Senior Geology students including the author, the rest of the field mapping and most of the levelling being completed by the author, working alone, during the following year (1936).

The area has been subdivided by the Lands and Survey Department, thus obviating the need for preliminary survey work. Detailed mapping of geological and topographical features was done in 1935 by chain and compass traverses, but when working alone the author relied entirely on pace traverses and frequent triangulation of bearings. Levelling sufficiently accurate for the drawing in of form lines was done by aneroid barometer, using the Trig. Station W.T. in the south-eastern corner of the area as the datum.

II.—PHYSIOGRAPHY.

A.—*General Relief.*

Topographically, this area varies from one of fairly young to early mature age of stream dissection, the rather close grouping of the form lines, as seen in the accompanying map, testifying to the high relief and rather rugged character of the country, particularly on the eastern side of the area. The streams are cutting down into portion of a table land, the Darling Plateau or Peneplain, the old level being clearly seen as laterite capped hills of a very constant height which never exceeds 900 feet. These laterite capped hills are a notable feature of the area; a large "island" of laterite with cliff-like edges showing deep embayments due to the headward erosion of the creeks, stands out in marked relief, a little to the west of the centre of the area, while

most of the south-eastern, eastern, and north-eastern, and portions of the extreme south-western boundaries of the area consist of laterite-topped highland.

According to Jutson (1913), the Darling Peneplain was uplifted in pre-Pleistocene, probably late Pliocene time, its western edge forming the Darling Fault Scarp. As a result of this uplift many streams were either dislocated or rejuvenated, and the present topography reflects this renewed cycle of erosion.

The principal drainage channels of the area have been formed by systems of small tributaries which feed either the Chittering Brook or one of its three major tributaries—Marda Brook, North Brook and Banksia Gully. The valley of the Chittering in this area is distinctly younger than the valley of the Upper Chittering which lies north of the area under discussion and which shows the lower relief and sweeping profiles of maturity.

B.—*The Chittering Brook and its Tributaries.*

1. *The Chittering Brook.*

The Chittering Brook enters the area at approximately the centre of its northern boundary and thence flows for about 1½ miles in a general south-easterly direction, by a series of irregular zig-zags alternately transverse and parallel to the strike of the country rocks. It then turns sharply S.W. following the changed strike of the country for half a mile when it swings southward. About half a mile farther on the Brook turns abruptly S.S.W. following the contact of a gneissic granite with felspathic quartzite for some twenty chains and then swings sharply S.S.E. into the granite and flows in a general southerly direction out of the area for one and a half miles to its junction with the Avon River.

The zig-zag nature of the northern portion of the Brook and its marked adjustment to the structure of the country throughout suggests that it may be either (a) a "superposed subsequent" stream (Cotton, C. A., p. 133); that is, an original stream which flowed in a general south-easterly direction on the duricrust or possibly upon other unconformable rocks of the Darling Peneplain, and which, following the Darling uplift, has cut down into the underlying metamorphics and accommodated itself to their structure, or—

(b) A consequent stream developed from an older drainage system of which the Upper Chittering may originally have formed a part, by uplift of the peneplain, the original south-easterly direction of flow being modified in recent times by adjustment to the structure of the rocks which it is traversing.

The Chittering Brook is a perennial stream and though very sluggish during the summer months, it flows rapidly during the wet season and is heavily laden with silt.

Along both banks there are traces of a terrace which varies from 0-5 chains wide at 10-15 feet above the present water level and suggests a recent rejuvenation of the stream, but as the brook very seldom overtops its banks no extensive deposits of alluvium are to be found in the area.

2. *The Tributaries.*

The tributaries of the Chittering Brook are for the most part small streams which flow only after heavy rains. There are, however, three nearly perennial though still intermittent tributaries: (a) Marda Brook, (b) North Brook on the left bank, and (c) Banksia Gully on the right.

(a) *Marda Brook and its Tributaries.*—This brook flows in a general west to east direction across the southern part of the area crossing the strike of the country until some 15 chains from its junction with the Chittering where it swings north-eastwards along the contact of gneissic granite and the metamorphics and then turns E. to join the Chittering just below the point at which that stream enters the granite.

Marda Brook is rather immature, with an unsymmetrical valley having steeper slopes on the north side in general than on the south side. Its tributaries are of two types—those which enter on the north side being short, straight, parallel, insequent streams of steep grade, cutting headward into the laterite "island," and those which enter on the southern side being, in general, longer and less regular, with lower grades. Of these No. 2 Creek can be seen cutting across the strike of the rocks except in its upper reaches where it swings south-east parallel to a broadly swerving outcrop of ferruginous mica schist. This south-western portion has much lower relief than the rest of the area.

(b) *North Brook* flows in a broad V-shaped valley near the northern boundary of the area. It swings from a curved north-easterly to easterly direction and joins the Chittering Brook at a point where it turns northward about 20 chains east of the turn-off of Plunkett's Road from the Lower Chittering Road. In its lower reaches, North Brook is fairly mature and flows through a terraced bed of alluvium.

This brook possesses a number of tributaries on both the northern and southern slopes of its valley, all of which are typically strike streams. The two most western of its tributaries, Contact Creek and Prospect Creek, are long, parallel, straight watercourses, running along geological boundaries and having rather steep V-shaped valleys. The divide between these two streams is a long straight ridge of porphyritic gneiss of a fairly constant height of approximately 700 feet.

Numerous small insequent tributaries on the eastward slope of Prospect Creek show marked headward erosion into the central laterite plateau.

(c) The creek which flows through *Banksia Gully* enters the area at its north-eastern boundary, flows due west across the granite gneiss and then describes an irregular arc facing southwards, and passing through a steep narrow gorge, travels on westward across the strike of the country rocks to join the Chittering. The tributaries of this stream are for the most part short and straight with a steep grade.

The other tributaries of the Chittering may be divided into two types:—

(1) Those on the eastern and central western slopes are roughly parellel insequent streams cutting into the laterite plateau whose boundaries form shallow cliff-like structures reminiscent of breakaways. (Talbot and Clarke, 1917, p. 43.)

Near their sources several of the streams on the eastern slopes are mature while in their middle parts the grade is steep, flattening out again in their lower levels. This is probably due to the fact that in their upper reaches, the creeks are traversing solid resistant granite, but farther westward they cross the contact of granite with the softer metamorphics. Here, owing also to the broken and jointed character of the rocks, erosion has proceeded rapidly and the streams have cut deep gorges, through which they plunge, to be checked at the foot of the slopes where they enter the Chittering.

(2) The tributaries of the north-western slopes, *e.g.*, Wilson's Creek and Camp Creek, are moderately mature streams which in part show some adjustment towards the strike and dip of their bed-rocks.

3. *Springs.*—Springs are of frequent occurrence in the metamorphic rocks of the area except in the gneissic granite country where they are seldom seen. They never occur on the laterite plateau which is well above the water table. During the summer months they are the most reliable sources of fresh water. They are most frequently found emerging from the cleavage planes of acid gneisses, or from the contacts of a basic dyke with gneiss. Occasionally on the slopes of the north central area several springs may be seen issuing at irregular intervals along a line of constant height. These springs have a remarkably constant flow. A large spring on the property of Mr. F. Wilson, about 15 chains S. of the Plunkett's Road Bridge, has been claimed to yield 6,500 to 7,000 gallons a day.

In the upper reaches of Wilson's Creek a spring of saline character issues from the boundary of a dolerite dyke although the water from a second spring in gneiss some 5 chains down stream is quite fresh. The water of the Chittering Brook is markedly saline in summer from the frequent presence of salts in solution in many of its tributaries, especially those which cross sheared and unsheared basic dykes. No analyses of these waters have, to the author's knowledge, been made.

4. *Sub-surface Drainage* (Aurousseau 1919).—A special feature of this area is the occurrence of underground drainage channels which open into the banks of the creeks. Their presence is revealed by an occasional "sink hole" and in one short easterly flowing tributary in the centre of the area a channel with a sectional area of over 4 square feet was noticed. These channels eventually collapse and are quickly scoured to form a new insequent tributary. In some of the cultivated areas so rapid is the denudation of the surface soils that farmers are faced with the grave problem of checking this waste. In two places in the southern half of the area small landslides of soil covering very steep dolerite talus slopes have occurred due to undermining of this subsurface drainage.

III.—GEOLOGY AND PETROLOGY.

A.—Structural Geology and Field Distribution of the Rocks.

1. *The Rocks.*—The rocks consist of a very complex series of metamorphics with later acid and basic igneous intrusives.

The metamorphics—the Chittering Series—are an apparently conformable series of gneisses, schists, and felspathic quartzites which frequently show but ill-defined boundaries one with another. All of these rocks show signs of fine crumpling or "drag folding" in different places. They strike typically north and south with local variations up to 45° to the east in the north-eastern corner of the area and there are traces of an arcuate fold in the outcrops of the central southern portion of the area. The dips are uniformly steep, being characteristically vertical, but vary from seldom less than 70° either to the east or to the west. The thickness of the different types is very variable and the bands are often rather impersistent along the strike, either disappearing under mantles of cultivated soil, or talus of the central laterite plateau, or lensing out at some points, whence often very little trace of them can be found. This is especially the case with the micaceous schists.

Cutting across the south-western part of the area, the contact line running in a constant north-east—south-west direction, is a medium-grained, typically-massive acid rock which appears to be a slightly crushed gneissic granite. Although the actual contact of this rock with the Chittering Series is obscured for the most part by rubble and talus slope, the boundary has been mapped as accurately as possible to within a chain or so. In general the boundary of this granitic rock appears to be roughly parallel to the strike of the adjacent metamorphics. This boundary line does not reflect the principal structural features of the Chittering Series and can be explained either as an unconformity or as the contact of an intrusive rock into the older metamorphics. However, in the extreme east of the area the granitic rock appears to be definitely intrusive into a micaceous schist and the general character of the rock in the field is that of an acid intrusive, while a microscopical study leaves little doubt of its igneous origin.

The rock extends to the east under the laterite outside the area studied for an unknown distance, and also appears to stretch some distance southwards, and may possibly be connected with the granitic rocks of the Upper Swan area. In the south, at its contact with the metamorphics, the granite shows some vertical jointing parallel to the boundary line, which gives it a vertically bedded appearance, but farther east it is quite massive, the outcrops occurring typically as low, gently rounded mounds or sloping floors.

The metamorphic rocks and the granite have both been invaded by acid and basic dykes. The acid dykes which are rare compared with the basic types, are biotite and muscovite pegmatites, graphic pegmatites, aplite and quartz veins. They are very irregular in size and distribution, and are usually traceable for short distances only. It is possible that there are two ages of pegmatites represented in the area, as in some of the acid gneisses are found irregular lenses and folded bands of a coarse pegmatite which appears to have suffered dynamic metamorphism along with the intruded rock, while in other places the pegmatites cut across the strike of the gneiss, and show little if any deformation.

The author is inclined to believe that there were two periods of acid intrusion, the first of which was the time of the "granitisation" of some of the schists, the apparent grading of the pegmatite into gneiss being a consequence of this process and the irregular folding seen in places being of "ptygmatic" type (Sederholm, J. J., 1923, p. 85, 1927, p. 25 *et seq.*), due to fluidal movements of the plastic injected rock. The younger pegmatite was probably the last phase of the intrusion of the gneissic granite.

The basic dykes have a general trend N.N.E., but in the south-western section of the area they swing round from N.E. to east. They are very numerous in the central and eastern parts of the area, but are less frequent on the western side of the central laterite plateau, while in the extreme western side of the area, in mica schist country, no dolerites at all were found.

The basic intrusives are of two types which are genetically related.

1. Dolerites and associated epidiorites.
2. Hornblende schists.

1. The dolerites and epidiorites form the principal type of dyke. They are very abundant and appear to radiate fanwise to the north and to the south-west from the centre of the area.

These dykes, some of which, to be exact, are vertical "sills," since they frequently follow the bedding-planes of the metamorphics, vary in width from less than half a chain to three or four chains; some are traceable for

more than a mile, while others can only be followed for a few chains; some branch and occasionally anastomose at junctions appearing to be quite continuous, with no sign of one branch cutting through the other, whence it appears that the dykes all belong to one period of intrusion. They are true "fissure dykes" (Sederholm, J. J., 1926, pp. 34-5), and have formed from the invasion of basic magma from below along cracks in granite and in the metamorphics. The dykes are usually finer grained along their edges than in the centre and the narrower dykes invariably have a much finer grain than the wide ones.

2. The hornblende schists occur in narrow dykes never more than a chain in width and rarely exceeding 30 chains in length. The field relations and microscopical examination of these rocks show that they were originally epidiorites which have been subjected to stresses producing an orientation of the predominant amphibole parallel to edges of the dyke, with the resultant schistose structure.

Many of the hornblende schists strike parallel to larger dolerite dykes, and in several places dykes have been found which show on either both or only one of their edges a definite schistose structure while their centres are massive, similar to medium fine-grained altered epidiorite. Also in places narrow dykes of hornblende schist appear to grade along their strike into massive fine-grained epidiorite.

The above statement, together with the fact that nowhere have the dolerites or epidiorite been found intersecting the hornblende schists seems to suggest that the basic dykes all belong to the same period of intrusion. Possibly during the intrusion the country was subjected to stresses which produced the schistose structure in some of the dykes. No parallel structures would be produced in the larger intrusions which were still in a fluid state, but many of the narrow dykes which were more rapidly chilled, and had already solidified, would have been unable to yield to the stresses as a liquid, but only by deformation of the still cooling magma, resulting in a parallel orientation of the amphibole perpendicular to the directions of stress.

Those dykes which show schistose structures along their margins but are more massive in their central parts may have yielded to the stress by recrystallisation at their edges and so protected their centres.

The relationship of the dolerite to the pegmatite intrusions is clearly seen in the south between No. 1 Creek and No. 2 Creek where two small dolerite dykes cut across an outcrop of graphic pegmatite, which is thus the older rock.

Later superficial deposits in this area are duricrust and alluvium. The duricrust is well developed in the central plateau and in the extreme southwest corner of the area. It is of two types:—

1. Pisolitic laterite typical of the Darling Range districts. (Simpson, E. S., p. 399, 1912, and Clarke, E. de C., 1919.)
2. Ferruginous grit.

The laterite is a high level form which occurs at a constant height of about 800 feet and is from 50 to 75 feet thick at its thickest parts. It appears to have developed equally well over all rocks. The ferruginous grit is seen in the form of loose boulders and broken fragments of dark red limonite in which are embedded grains of quartz and muscovite. This grit occurs on the slopes below the pisolitic laterite and may possibly be compared with the ferruginous sandstone found in the Upper Swan area (Fletcher and Hobson, 1931-2).

Alluvium is present in a narrow strip along the flood plain of the Chittering Brook.

2. *Structure.*—The complicated and often highly folded nature of certain of the rock types, the frequent difficulty of following geological boundaries, and the rapid variation in mineralogical composition of the metamorphics, both across and along the strike, make one very cautious in attempting to elucidate the structure of the area.

Probably a great deal more field work and mapping, particularly of areas to the west and east of the present locality will be required before the key to the true interpretation of the major structures will be obtained.

A study of the minor drag folds in certain parts of the area has suggested explanations of portions of the structure but no doubt more detailed examination of the dragfolding in adjoining areas would furnish many valuable clues as to the ultimate structure of the metamorphics in this district.

Unfortunately much of the dragfolding in this area is so involved that a reliable interpretation of it appears well nigh impossible. The folding throughout the area has been intense, the angles of dip of the various rocks rarely being less than 70° and most commonly being over 85°. The strike varies from a little east to slightly west of north.

Readings of good dragfolding, about 20 chains south of Wilson's House, in biotite gneiss near a garnet gneiss band, suggest that this part of the area is on the eastern limb of an anticline slightly overturned to the east and pitching at about 40° to the south.

About 20 chains south of Marda Brook between No. 1 and No. 2 Creek is an area of a similar type of gneiss which is very contorted. The outcrops here swing round in a fairly narrow arc with convexity facing south from a strike of 45° at a point on the eastern side to 330° at 16 chains due west of this point. Readings of a dragfold at this point confirm the impression that this part of the area is the nose of an anticline pitching fairly steeply to the south. About 25 chains to the south-west is a band of ferruginous mica schist which swings from a north-westerly to a northerly strike and appears to be part of the same structure.

If this part of the area has a pitching anticlinal structure as suggested then the broad bend of felspathic quartzite near the junction of Marda Brook and Chittering Brook may be interpreted as a large dragfold. A highly idealised plan, showing this suggested structure, has been prepared (page 39).

B.—*The Metamorphic Rocks.*

The metamorphic rocks exposed in this area are probably an extension of what has been called the "Jimperding Series" (Clarke, 1930, p. 12). They constitute a very varied and irregular series of interbedded gneisses, micaceous schists, sillimanite and kyanite schists, and felspathic quartzite, which attain a possible thickness of 4,500 to 5,000 feet in the area mapped, though they are known to extend for at least a mile west of the western border of this area. These rocks form part of a belt of very ancient metamorphics which are probably of Yilgarn age. The belt extends eastwards to link up with the Jimperding metamorphics which have a predominant east-west strike and are characterised by thick beds of quartzite with interbedded gneiss, basic schist and micaceous schist, with gentle folding to the south (Prider, 1932-4). Farther east of Jimperding these metamorphics frequently show clear evi-

dence of much stronger dynamic metamorphism, being thrown into steep folds, and the beds show considerable variation in thickness.

The metamorphic belt extends northwards from the Chittering Valley to Moora and some 110 miles north of this in the Irwin River district near Yandanooka are further occurrences of similar metamorphic rocks.

The belt stretches south-east from Jimperding to Clackline and extends to York. Another occurrence has been noted (Maitland, 1899, p. 28) between Northam and Goomalling.

Owing to the intensely folded and metamorphosed nature of the rocks, it is very difficult to determine the succession or the order of the beds in such a comparatively small area.

A few miles to the south-west of the area mapped are deposits of the Bullsbrook (? Jurassic) leaf beds but no sign of such beds were found here.

The predominant rock is a medium grained biotite gneiss which in places shows signs of intense folding and which occurs irregularly throughout most of the area, while interbedded with this gneiss are high-grade metamorphics, such as the sillimanite and kyanite schists, and garnet gneisses.

The metamorphics may conveniently be divided into—

1. The schists—micaceous, and basic.
2. The gneisses.
3. The "quartzites" or acid mylonite-gneisses.

This arbitrary division of the metamorphics is petrologically a rather artificial one as some of the members of the first group are more closely related to certain types of gneisses than to any other member of the schists, while structurally the division between a gneiss and a schist is frequently more apparent than real. However the grouping has the charm of comparative simplicity and for that reason has been adopted here.

1. *The Schists.*—These may be grouped as—

Micaceous schists consisting of—

(a) Sillimanite, kyanite schists.
(b) Lenticular mica schists.
(c) Ferruginous mica schists.

Basic Schist—Hornblende schist.

Micaceous Schists of the Lower Chittering area include an assortment of types extending from rather massive gneissic on one hand to highly laminated schistose on the other. There are marked differences in the mineral assemblages of the different groups in some cases, while in others there appears to be a gradual transition of one type into the other, indicating differing degrees of regional metamorphism in the area. There appear, however, to be several clearly marked horizons of schists. All these rocks have suffered rather intense weathering and fresh hand specimens are difficult to obtain.

(a) *The sillimanite—kyanite schists.*

This type ranges from rock which carries sillimanite with only accessory kyanite to one in which kyanite is present to the exclusion of sillimanite. The commonest type shows about equal development of both these minerals. The specific gravity varies considerably in specimens showing different stages of weathering, but the freshest range from 2.75-2.82.

In freshest hand specimens the micaceous schists vary from rather massive gneissic to finely schistose types of greyish white colour generally

slightly stained with limonite. They consist of an abundance of medium fine granular quartz and interstial flakes of biotite of average grain size between 1 and 2 mms.

The sillimanite occurs as small, flat, yellowish-white coloured, soft furry plates with a typical silken lustre. These plates range from less than 1 mm. to 7 mms. in diameter and are oriented in the plane of schistosity. Kyanite is usually present in thin, elongated parallel plates, pale yellowish to colourless, up to 3 mms. in length which are frequently very difficult to recognise in hand specimen.

In thin section the texture is granoblastic, gneissic, seriate. The interstitial quartz grains frequently form a clear interlocking mosaic characteristic of recrystallisation textures. Kyanite crystals usually show diablastic structures, partially or completely surrounding rounded grains of quartz which have been enclosed during the growth of the kyanite and which indicate an early stage of crystalloblastic development. (Figs. 1 and 3.) Both kyanite and sillimanite are very frequently partially surrounded by, or embedded in, flakes of pale green-brown biotite in a manner which generally indicates a progressive metamorphism.

The sillimanite occurs in characteristic felted, or sheaf-like aggregates of elongated needles showing typical cross fracture, and is invariably associated with biotite. In one specimen (15385),* a kyanite sillimanite schist, sillimanite occurs in two markedly different sizes—rather coarser straight needles .02 mms. wide and up to 1.5 mms. long and also in fine acicular brushes embedded in biotite. (Fig. 2.) This suggests two distinct generations of the mineral (Harker, p. 324).

Biotite is an abundant constituent of all these rocks and occurs in irregular green-brown flakes which frequently carry strongly pleochroic haloes surrounding inclusions of zircon. These zircons which range from .03 mms. to .35 mms. in length are dark in colour and have rounded outlines.

Chlorite occurs occasionally in pale green, often radiating, laths pseudomorphous after biotite, indicating retrograde metamorphism. Staurolite was noted in a few specimens. It occurred in numerous small, yellow, pleochroic lath-like crystals up to .24 mms. long generally seen associated with crystals of biotite and chlorite.

In some types colourless micas, muscovite altered from biotite, and irregular fibrous flakes of sericite suggesting stress conditions, are fairly abundant. A little finely twinned sodic plagioclase felspar associated with quartz is present in a few specimens.

(b) *Lenticular mica schist.*—This type occurs in one fairly persistent band some 8 or 9 chains wide and about a mile long in the north central portion of the area and in several small apparently isolated bands in other parts. The schists consist essentially of masses of flakes of colourless muscovite and pale greenish biotite, oriented to produce a strongly schistose or foliated structure in the rock. Intercalated in bands which pinch and swell irregularly is abundant granular quartz. The foliation planes of the mica curve around these irregular hard bands producing a peculiar "knotted" or lenticular structure in the schist. These lenticles vary from 3 cms. diameter to finer ripples less than 1 mm. in diameter.

* The figures in parentheses refer to catalogued specimens in the General Collection at the Geology Department, University of W.A.

A heavy mineral separation undertaken on one of these rocks produced abundant small dark, rounded prismatic crystals of zircon, one or two grains of kyanite, and a little staurolite.

(c) *Ferruginous mica schist.*—This rock occurs in the southern portion of the area. In hand specimen it is medium-fine grained and red coloured, due to the coating of all its constituents by iron oxide from weathering. It consists essentially of granular quartz and intercalated flakes of colourless mica oriented to produce a marked fissility. Numerous small flat plates of a soft whitish mineral are seen scattered throughout the rock in parallel orientation. Although this has the habit of sillimanite, powdered fragments examined microscopically showed no sign of the characteristic form and cleavage of that mineral, but on the other hand showed the form, cleavage, and low refractive index of sericite.

In thin section the rock is granoblastic schistose consisting of intercalated bands of interlocking, iron-stained quartz; associated biotite in shredded red-brown flakes; subhedral colourless muscovite; and colourless, fibrous sericite. The sericite occurs in frequent roughly continuous parallel oriented bands interstitial between quartz and biotite, and is possibly a pseudomorph after sillimanite.

Basic Schists:

Two distinct types of hornblende schist have been recognised in the area. The predominant, clearly of igneous origin, and found in the field intrusive into the gneisses, will be described later.

A few occurrences of a second type, a rather sandy hornblende schist, in places minutely foliated, and apparently embedded in the biotite gneiss, have been noted. This is a dark coloured, fine, even granular rock in which fine intercalated layers of quartz and short needle-like hornblende crystals form finely folded laminae. The crests of these minute folds are filled with coarser crystals of hornblende, individuals of which attain a length of 1.5 mms. The specific gravity is 3.00.

In thin section the hornblende consists of elongated prisms with blue-green pleochroism and is a fairly high grade amphibole with refractive index ranging from 1.665-1.675. The bluish colour is caused by the presence of soda and the mineral probably has a composition tending towards glaucophane.

Magnetite in numerous broken and parallel oriented grains is associated with the hornblende. These minerals are set in a mosaic of clear, recrystallised quartz, with a little twinned oligoclase felspar. Accessories are minute zircons, producing pleochroic haloes in the hornblende, a little apatite, and granular epidote.

2. *The Gneisses*:

The main bulk of the central part of the area consists of massive to finely banded acid rocks which range in mineralogical composition from highly acid types (approaching quartzites) to intermediate hornblendic varieties in which are found in one or two places, basic bands of a gneissic biotite hornblendite granulite.

The gneisses are divisible into the following types:—

(a) Biotite Gneiss.
(b) Hornblende Gneiss.
(c) Garnet Gneiss.
(d) Augen Gneiss.
(e) Hornblendite Granulite.

The first three types frequently appear, in the field, to grade into one another and are apparently interbedded with the schists. The augen gneiss forms a clearly defined band between 25 and 30 chains wide, extending the length of the area on the western side, bounded on one side by a micaceous sillimanite schist and in part on the other by a quartzitic slate.

(a) *Biotite Gneiss.*—This group included a series of acid rocks which show marked structural and textural differences but less varied mineral compositions. In the field some parts are found to be finely crushed, laminated, and drag-folded; others, less disturbed, and massive. The most abundant type is a medium fine grained, light grey coloured, rather massive, granitic gneiss with an average specific gravity of about 2.74. Frequently in hand specimen the gneissic banding is not very apparent. Other varieties often show a rather irregular porphyroblastic structure.

The texture of all these types is holocrystalline gneissic. In thin section they are granoblastic to porphyroblastic, and in some cases, porphyroclastic, gneissic. Recrystallisation, possibly with the addition of silica, potash and soda by granitisation processes, appears to be the predominant characteristic of some types, while in others granulation due to shearing stresses is a marked feature. The principal mineral components are quartz, in clear grains of varying size; sodic plagioclase, albite to oligoclase, generally in larger allotriomorphs, showing characteristic twinning and frequently carrying inclusions of apatite rods and the alteration product, sericite.

Microline occurs in subordinate amount in some specimens and when present bordering plagioclase generally shows the development of myrmekite. A little orthoclase is also occasionally seen. Biotite is abundant in oriented idiomorphic laths and flakes of green to brown colour, often arranged about the rims of crystalloblastic felspars (Fig. 6). It is typically fresh and unaltered and rarely contains inclusions of zircons with pleochroic haloes. Subhedral muscovite flakes are occasionally abundant. The accessories are apatite rods in felspar and biotite, broken crystals of iron ore, granular epidote, zircon occasionally in biotite, and a little sphene.

(b) *Hornblende gneiss.*—This type occurs apparently interbedded with biotite gneiss and appears to grade into bands of garnet gneiss in several places. In hand specimen this rock is medium grained, black and white coloured, consisting of intercalated layers of quartz and felspar, and oriented fine hornblende plates, and flakes of biotite producing a marked gneissic structure. Grain size is variable.

In thin section it is granoblastic gneissic to cataclastic, and consists essentially of bands of irregularly oriented crystals of hornblende up to 1.6 mms. long intergrown with brown biotite laths, set in a ground mass of broken irregular grains of quartz, potash and soda felspar.

The felspars are microcline, and twinned and untwinned albite-oligoclase, and associated with this is a little vermicular myrmekite formed at the borders between soda and potash felspars.

Accessories are epidote, iron ore, in the form of ilmenite often rimmed with sphene, rounded prismoids of zircon, and a little apatite.

(c) *Garnet Gneiss.*—The garnet gneisses of this area are divisible into two distinct types (I.) Garnet Hornblende Gneiss, (II.) Garnet Staurolite Chlorite Gneiss.

(I.) *Garnet Hornblende Gneiss* is present as a narrow band in hornblende gneiss, which grades into biotite gneiss in the north centre of the

area. It is a black and white strongly banded rock consisting of alternate layers of quartz and amphibole. Scattered through the femic bands are abundant fractured crystals of red garnet ranging from 2 mms. up to about 8 mms. in diameter.

In section this type is similar in all respects to the normal hornblende gneiss described above, except for the addition of the pink garnet, which is probably almandine in rather shattered crystals generally associated with hornblende in a diablastic texture.

(II.) *Garnet-Staurolite-Chlorite Gneiss* in hand specimen, consisting of an aggregate of oriented quartz and black mica through which are scattered numerous crystals of broken, red garnet of variable size. In thin section the rock is granoblastic gneissic. The mineral constituents are:—quartz, which forms a background of an irregular interlocking mosaic; biotite in green brown plates altering to chlorite, occasionally with inclusions of iron ore, and zircons producing pleochroic haloes; chlorite, in abundant pale green sheaves, occasionally associated with biotite and frequently completely enclosing grains of pink almandine (Fig. 4). Staurolite is present in irregular groups of numerous short stumpy crystals frequently associated with biotite and chlorite. Accessories are iron ore (magnetite), granular epidote and rounded zircons.

The staurolite in this type appears to be quite fresh and in an early stage of development, while both the garnet and the biotite are altering back to chlorite.

(d) *Augen Gneiss.*—This type is coarsely crystalline, light grey coloured, consisting essentially of irregular bands or lenses of felspar up to 15 mms. wide and generally twice as long. These lenses are all roughly oriented to form a coarse "augen" structure, the interstitial material being a finer granular aggregate of quartz, felspar and biotite. The specific gravity averages about 2.72.

In thin section it is porphyroclastic gneissic with a cataclastic granular matrix.

The porphyroclasts consist of:—orthoclase in large plates up to 7 mms. long and 4 mms. wide; albite, and microcline, in smaller rectangular plates roughly 1.2 mms. in diameter. The plagioclase is usually rather turbid with alteration to kaolin and sericite, while microcline is characteristically fresh and shows irregular cross-hatching. The matrix consists of an aggregate of broken crystals of quartz, albite, microcline, and a little orthoclase, shredded flakes of brown biotite, undulating muscovite and fibrous sericite associated with granular epidote. Running through the matrix are a number of parallel, strongly mylonitised bands in which the felspars are almost entirely altered to flowing aggregates of sericite, with quartz and sphene, and one section was found to contain a single crystal of calcite.

(e) *Hornblendite Granulite.*—In this group have been placed two types of basic gneissic rock found in several irregular bands or segregations in biotite or hornblende gneiss.

One type is heavy, melanocratic, medium grained, and consists almost entirely of rather coarse crystals of hornblende, with accessory quartz, iron ore, epidote, and rounded zircons forming pleochroic haloes in the hornblende.

The second type is more acid and consists of intergrowths of hornblende crystals up to 1 mm. x .5 mm., with fresh laths of biotite up to .8 mm. long. Interstitial material is albite, oligoclase felspar, granular quartz, and sphene forming rims about ilmenite.

Accessories are: apatite, zircon producing pleochroic haloes in both hornblende and biotite, rutile. The mineralogical composition and texture of this type suggests that it is a basic segregation of igneous origin.

3. *The "Quartzites."*

The definition of quartzite (Hatch & Rastall) as "a recrystallised sandstone in which all the original structures are destroyed and the whole is converted to a mosaic of clear formless quartz crystals without any regular outline but with closely interlocking, crenulated edges," can very seldom be said strictly to apply to the very acid quartzose types of rock described below.

Cataclastic rather than granoblastic structures are predominant and the term "mylonite gneiss" of Quensel (1916) which is "a rock partly granulated and partly crystallised, intermediate in its characters between mylonite and schist. The felsic minerals show cataclastic phenomena without much recrystallisation, and often surrounded by, and alternating with, — — — recrystallised dark or mafic minerals," would appear to be more applicable in many cases, and quartz-felspar-mylonite-gneiss would probably be a more accurate, though rather cumbersome, name for felspathic "quartzite." However, the term "quartzite" will be used here in the description of these acid metamorphics which may show both cataclastic and recrystallisation structures. They may be divided into:—

(a) Felspathic "quartzite."
(b) Epidote "quartzite."
(c) Quartzitic slate.
(d) Fine grained quartzite.

(a) *Felspathic "quartzite."*—This type occurs persistently in a band about 15 chains wide and running for about three miles in a north-easterly direction on the eastern side of the area. It varies from a fine-grained cherty rock pale green in colour, carrying fine even bands of epidote, to a rather coarser grained yellow rock consisting of a granular aggregate of quartz, felspar and epidote. All types are flecked with small crystals of pyrite.

In thin section the finer grained types consist almost entirely of recrystallised equidimensional quartz averaging .08 mms. in diameter with fine oriented continuous stringers of epidote.

The coarser varieties show considerably less recrystallisation of the quartz, and contain abundant porphyroclasts of albite felspar which may show minute faulting (Fig. 5) and occasionally a little microline. Epidote may sometimes form irregular subhedrals crystals up to .3 mms. long.

(b) *Epidote "quartzite."*—This rock type occurs in a single thin band less than two chains wide and traceable for a distance of eight to ten chains along a north-south line in the centre of the area. The band shows a rapid increase of basicity across the strike from west to east, hand specimens being considerably darker in colour. The rock is medium grained, even granular, in hand specimen the minerals recognised being quartz, pale yellowish epidote, and parallel needle-like hornblende.

In section the rock consists essentially of a granoblastic aggregate of idioblastic granular to subhedral epidote with a birefringence ranging from that of pistacite to clinozoisite and zoisite, crystals being up to 3.5 mms. long, set in a matrix of interlocking quartz grains, averaging .9 mms. diameter, with subordinate blue-green hornblende, chlorite associated with epidote, and sphene in small granules. Accessory minerals are rounded prisms of apatite and zircon and a little iron ore.

(c) *Quartzitic slate.*—This type, which occurs in a region of strongly folded rocks in the western side of the area, is itself minutely contorted and dragfolded, and in hand specimen appears as a very fine grained, dark green coloured, finely laminated sediment, regularly foliated and contorted. It has a fine slaty cleavage along intercalated layers of dark flakey material and fine white coloured quartzitic bands. Irregular cubes of pyrite are scattered throughout.

In thin section the rocks consist essentially of layers of microcrystalline to cryptocrystalline quartz and felspar, and shredded chlorite, intercalated between fine bands of very fine grained quartzite.

(d) *Fine grained quartzite.*—This rock occurs in thin bands or lenses in mica-sillimanite schists, augen gneiss, and the quartzitic slate. It is very fine grained, massive, pink and white coloured. and consists entirely of fine interlocking, equidimensional, angular crystals of quartz averaging 0.1 mms. in diameter.

C.—*The Igneous Intrusives.*

The igneous rocks of this area are all intrusive into the metamorphics of the Chittering Series and they may be subdivided as follows:—

Acid intrusives
- (a) Gneissic granite.
- (b) Aplite and associated pegmatites.
- (c) Quartz veins.

Basic intrusives—
- (a) Massive type—Dolerite and associated epidiorites.
- (b) Schistose type—Hornblende schists.

Acid Intrusives.

(a) *Granite (gneissic or stressed).*—The granite type of acid rock which in the field appears intrusive into the metamorphics is a medium grained type which shows a very constant mineralogical composition throughout its breadth in the area, in marked contrast to the acid gneissic metamorphics. In the structure this rock varies from a massive medium grained crystalline type in which rather irregular shredded flakes of biotite are distributed in irregular parallel bands, to a finer grained slightly darker coloured massive allotriomorphic granular rock in which any gneissic banding seen in hand specimen appears to be due to granulation by stress.

In the more granulated specimens secondary epidote is fairly abundant. The minerals of this rock as determined in thin sections are:—

Quartz—abundant in all specimens, occurring usually as irregular anhedral grains of varying size from large crystals up to 1.5 mms. diameter often showing undulose extinction, to small broken grains which are usually present as interstitial growths between felspars. The felspars are:—

Microcline is very abundant occurring in fairly fresh clear plates up to 1.55 mms. in diameter. Plates occasionally have embayed edges filled with quartz but very seldom carry myrmekite. It is usually fresh but some alteration to fibrous sericite may be seen. Frequently the "cross hatched" twinning is very irregular. Orthoclase in large subeuhedral rectangular plates up to 2 mms. diameter is frequently present. These plates often show considerable alteration to aggregates of granular sericite, epidote and kaolin, the inclusions of sericite occasionally being grouped thickly in a zonal band parallel and close to the rim of the felspar crystal.

Plagioclase occurs in numerous euhedral to subhedral crystals of variable size which may show zoning. The plagioclase is invariably rather heavily saussuritised and consists of a mat of sericite, zoisite, and epidote flakes. Original twinning in fine lamellae is frequently visible and extinction angles indicate albite—oligoclase.

The ferromagnesians are essentially biotite, muscovite and epidote. Biotite occurs typically in irregular greenish-brown, often rather altered pleochroic flakes and laths generally associated with granular epidote, and may carry inclusions of magnetite granules. In most specimens plates of brown biotite were found in which were dark needle inclusions of rutile arranged in an interlaced web structure known as sagenite webbing. Inclusions of zircon with strong pleochroic haloes, are also to be seen.

Muscovite is present usually in medium sized fresh sub- to euhedral plates and flakes in which can be distinguished two types, primary crystals idiomorphic towards epidote and biotite, and secondary, generally smaller laths, frequently showing alteration from biotite.

Epidote is a frequent mineral and is mainly secondary, occurring as granular aggregates associated with and generally forming from biotite. It is a pale yellowish mineral and is common epidote. One crystal associated with biotite with sagenite webbing shows similar webbing in its core. Epidote also occurs in veinlets cutting the felspars and quartz. Zoisite is abundant in fine granular aggregates in saussurite. Accessories are apatite, in abundant small rods and prisms; zircons, and rutile, are frequently included in biotite; iron ore occurs in occasional grains scattered through altered biotite or surrounded by a rim of epidote.

One or two specimens show development of a little myrmekite in microcline. In thin section, the similarity of this rock type to the gneissic granite of the Darlington Area is most marked.

Sagenite Webbing.—An interesting point in connection with this gneissic or granulated granite type, is the frequent occurrence in biotite of interlacing acicular needles of rutile which form sagenite webbing.

This webbing, which is probably due to heating of original biotite with the separation from it of its titanium content, in the form of rutile, has not been found in the biotite of any of the biotite gneisses of other metamorphics from the area under discussion, but appears to be a constant feature of the granite.

The occurrence of sagenite webbing has been remarked in the gneisses of the Jimperding area (Prider, 1932), which, it was suggested, may have originally been sediments. It has since been found in all the acid gneisses of the metamorphics in the areas, south and east of Toodyay, which have been mapped by University students during the last four years.

Sagenite webbing in biotite has also been noted in "grey granite" from the Upper Swan area (Fletcher & Hobson, 1931-2), but there appears to be no mention of its occurrence in the granite of the Darlington and Roleystone Areas.

(b) *Aplite and Associated Pegmatites.*—These are later than the granite and the metamorphics which they intrude. Occurrences of aplite in the field are rather rare, one specimen (1556) which was found in close proximity to a graphic pegmatite shows a fine-grained granular structure in hand specimen, and in section is seen to consist of medium fine-grained allotriomorphic granular clear quartz, and slightly altered albite-oligoclase felspar together with one or two flakes of altered biotite and granular epidote.

The pegmatites proper are of several varieties which consist essentially of coarse textured crystalline quartz and alkaline felspar, usually microcline, with a variable development of muscovite or biotite in coarse books which may measure from ½ inch to 2 inches in diameter and up to ½ inch thick. One biotite pegmatite (1551) carries numerous small dark segregations of magnetite up to ¾ inch in diameter. Several graphic pegmatites are present in the south. These consist of linear intergrowths of clear quartz and yellowish white microcline.

(c) *Quartz Veins.*—Vein quartz is very irregular in distribution and rather rare in occurrence in the area. As yet the relation of the quartz veins to the pegmatites is uncertain but the veins in the Chittering Series frequently show signs of some deformation and it is probable that they closely followed the aplite-pegmatite dyke phase.

An interesting occurrence of vein quartz has been noted in the western portion of the area in quartzitic slate on the site of an old prospecting "show" or costeen. The quartz is clear, colourless, massive crystalline and heavily sprinkled with pyrite in cubic crystals of varying size ranging from a fine "paint" coating cracks in the quartz to perfect single cubes and pyritohedrans 6-7 mms. in diameter.

Broken faces of these cubes which have been exposed to weathering for some time show brassy to bluish tarnishing indicative of the presence of copper. Blowpipe tests and also a number of wet-way tests carried out on fragments of this mineral failed, however, to provide any positive reactions for copper.

The Basic Intrusives.

The basic dyke rocks are all holocrystalline fine to medium grained with seriate texture, and with a colour varying from black to greyish green in the highly uralitised varieties. The dyke rocks may be divided into:—

(a) Massive types—Dolerites and Epidiorites.

(b) Schistose types—Hornblende Schist derived from (a) by dynamic stress.

(a) *The Massive types.*—Dolerites and quartz-dolerites. These are black, holocrystalline, generally medium grained, and in hand specimen can be recognised black pyroxene and light coloured, translucent, plate-like felspar. In thin section ophitic texture is well marked.

The minerals recognised are:—

Pyroxene: in subhedral to euhedral crystals, pale brownish to colourless, only faintly pleochroic. Cleavage is well marked and relief is high, extinction is variable. In sections with oblique extinction biaxial figures, which show that the section is nearly perpendicular to the acute bisectrix, are obtained, while sections with straight extinction give a figure characteristic of the emergence of an optic axis. The optical character is always positive. The relation of biaxial figure to extinction suggests a monoclinic pyroxene with small axial angle is probably enstatite-augite (Thomson, 1911, p. 305). Simple twinning is frequent. Even in freshest specimens the pyroxene shows alteration around the rims to pale green fibrous uralite.

Felspar: occurs in laths and plates of a marked dusty brown colour, which are ophitically intergrown with the pyroxene. These show the fine lamellar twinning of plagioclase, and sections cut perpendicular to the twin planes show extinction angles averaging about 24° and hence the felspar is labradorite.

Quartz: is present in the quartz-dolerites as small interstitial crystals associated with felspar.

Iron Ore: occurs frequently in abundant euhedral to skeletal crystals or subhedral grains of magetite with synantetic reaction rims (Sederholm, J. J., 1916) of green chlorite and ilmenite in skeleton crystals which may show incipient alteration to leucoxene.

Primary hornblende: occurs in subordinate amounts as dark green pleochroic subhedral crystals.

Brown biotite: occurs in a few irregular plates in some sections.

Accessories: apatite in short stumpy crystals or elongated needles most frequently occurs as inclusions in quartz in the quartz-dolerites; zircons are rare.

Epidiorites.—The mineral assemblage in this group is essentially the same as the dolerites, the chief difference being the much greater development of the secondary minerals, particularly uralite, and leucoxene from alteration of the primary pyroxene and ilmenite respectively, and frequently accompanied by almost complete destruction of the original ophitic texture.

Other secondary minerals are pale green chlorite growths forming by further alteration of uralite frequently intruding into the adjoining altered felspars. In many types which are in advanced stages of uralitisation the felspars may be completely altered to saussurite in mat-like intergrowths of granular zoisite, epidote, sericite, and fibrous chlorite which entirely mask the original form of the felspars.

Secondary sphene, forming borders around cores of ilmenite may also be seen occasionally. Secondary epidote may be produced in abundance replacing the saussurite in the alteration of plagioclase, one specimen (15358) being seen in section to consist almost entirely of epidote, fibrous uralite and chlorite, and leucoxene with subordinate granular quartz, and abundant accessory apatite.

There is no definite boundary line, either petrographical or in the field, between the dolerites and epidiorites. They form a continuous series of which dolerite and completely uralitised dolerite or epidiorite, are the two end points and all intermediate stages in the uralitisation are represented.

(b) *Schistose Type*—Hornblende schist.—This type is generally a medium-fine grained, dark green rock with a finely schistose structure, consisting of fine, needle-like parallel-oriented crystals of dark amphibole, irregularly scattered through which are irregular, small, even granular, white coloured flakes of felspar. In the field this schistose rock has been found to form the borders of some dykes, the centres of which are massive epidiorites.

A petrographical study of these schists leaves no doubt that they have been formed directly as the result of shearing of original typical epidiorites or dolerites.

In thin sections cut perpendicular to the plane of schistosity, may be seen specimens ranging from partially sheared and granulated epidiorites which show medium grained "augen" of unbroken epidotised plagioclase surrounded by parallel-oriented "flowing" fibrous uralite (1528), to a fine grained finely schistose type in which the presence of abundant granular zoisite intercalated with uralitic hornblende, is the only trace of the original plagioclase (15316).

The less altered varieties may contain fairly fresh, slightly dusty felspars, with broken edges, and associated with these is amphibole in subhedral

to euhedral, fresh blue-green, pleochroic laths, with a refractive index ranging from 1.668 to 1.674, and which is probably a glaucophanic variety. This is probably produced by recrystallisation from original uralite, with absorption of some soda from the felspar. The epidote and zoisite occurs in granular aggregates, with epidote also occasionally in larger crystalloblasts of pale yellow-brown colour.

The plagioclase when fresh, usually shows the cloudiness characteristic of the felspar in the dolerites, and the extinction angles of lamellar twins indicates a composition near that of labradorite. The felspars more often show, however, almost complete alteration to granular epidote, zoisite and fibrous chlorite. Chlorite is present in pale green fibrous shreds, in examples of the early stages of alteration but is not found in the more completely sheared types.

Iron ore is an abundant accessory occurring as small euhedral crystals of magnetite and more frequently irregular, broken, and lensed out granules of ilmenite surrounded by rims of granular sphene.

Quartz may occur abundantly in granulated aggregates intercalated between bands of epidote, and may be partly primary, derived from original quartz-dolerites, and partly secondary from the epidotisation of the plagioclase.

Apatite is frequently present in needles and short crystals embedded in quartz and altered felspar. Zircons giving pleochroic haloes in the hornblende are rarely present.

Clouded Felspar.- An interesting feature of the felspars of the basic igneous rocks in the area is that especially in the dolerites, whilst remaining perfectly fresh, they show a peculiar dusty-brown clouding by a substance so finely divided as to be unrecognisable even under very high power microscopes. These felspars are intermediate plagioclase with a composition approaching that of labradorite. In the epidiorites this brown clouding is frequently a marked feature of the fresher felspar, though it may be quite masked in many cases by the development of saussurite.

In the less strongly sheared epidiorites, some broken crystals of felspar may show clouding, but in those hornblende schists, in which dynamic metamorphism has been rather more intense and has been accompanied by recrystallisation of the felspar, the new crystals are perfectly clear and unclouded.

These phenomena agree closely with the occurrences of clouded felspar in metamorphosed dykes of Scourie District, Sutherland, Scotland, as described by A. G. MacGregor (1931).

MacGregor suggests that the dusty inclusions are due to a heating up and baking of the basic intrusives at some period after their consolidation. This baking causes minute traces of iron oxide (always present in the more basic plagioclases) and water, to separate out and cloud the felspars. Subsequent more intensive dynamothermal metamorphism has caused the breaking down of the original felspars, which have recrystallised unclouded. This opinion has more recently been confirmed by G. A. Joplin (1933), working in New South Wales.

D.—Later Rocks.

1. *Duricrust.*—A brief statement of the distribution of the duricrust plateaux in the area has already been given. The deposit is of two distinct types—the pisolitic variety of laterite which has been fully described from

other Darling Range areas, and a ferruginous grit which is found at a lower level and which possibly underlies the ubiquitous laterite type. This ferruginous grit is probably comparable with the ferruginous sandstone of the Upper Swan area (see above). The grit consists of numerous irregular, rounded and angular, grains of white quartz up to 10 mms. in diameter and occasionally small flakes of muscovite set in a dark red ferruginous matrix of fine grain. It is found overlying various types of both igneous and metamorphic rocks and appears to develop particularly well over ferruginous mica schist.

It appears as one progresses up the hill-slopes, to grade into laterite at between 750 feet and 800 feet. Most probably the iron in both the grit and the upper laterite was ultimately derived from the same source.

2. *Talus Slopes.*—Many of the steeper slopes in the area are covered with thick mantles, occasionally showing a terraced formation, of rubble or talus produced by the disintegration of dolerite, granite or gneiss. In some cases these talus slopes have been partly covered by loose soil. Heavy rains frequently cause land slips of this unconsolidated material, which is therefore unsuitable for cultivation and in places where the vegetation has been removed, presents a serious problem for the farmer.

3. *Alluvium.*—Mention has already been made of the presence of alluvium along the flood plain of the Chittering Brook. The stream is still actively degrading its bed, however, and only small deposits of alluvium are to be found. During flood periods, rise in the level of the Avon River tends to dam back the waters of the Chittering, which may deposit some of its coarser material, but the pressure is quickly released by the Avon, and the resultant rapid scouring action of the Chittering removes most of this silt. Such action during phenomenal floods may have been responsible for the terraces in some parts of the Lower Chittering Valley.

IV.—THE METAMORPHISM AND ORIGIN OF THE CHITTERING SERIES.

As previously stated, the Chittering Series is an assemblage of metamorphic rocks which conveniently fall into three main groups:—

Schists,
Gneisses,
Quartzites.

Any discussion of the origin of these rocks must primarily be dependent for its conclusion upon the recognition of the type of metamorphism which has been at work, and upon a proper interpretation of the products of such metamorphism as exposed in the area to-day.

A.—The Metamorphism.

The regional metamorphism in this area appears to have been rather complex, varying in grade and intensity over quite small areas. There can be seen all gradations from that characteristic of the "epizone" conditions of Grubenmann (1910) where temperature is moderate, hydrostatic pressure low, and shearing stress is the chief agent of metamorphism, to that of the deep seated types of the "katazone," where temperatures and pressures have been high, and stress has played a relatively unimportant part.

Among the crystalline schists, the minerals chlorite, biotite, hornblende, garnet, staurolite, kyanite and sillimanite, are present. These have been

used by Barrow (1912) and Tilley (1925 and 1930) to distinguish well marked zones of thermal metamorphism of original argillaceous sediments in the Highlands of Scotland.

The distribution of these index minerals in the Chittering Series appears to be rather sporadic and no definite zones of metamorphism have yet been recognised. Probably, with extended mapping of the district, gradations in metamorphism, characterised by the predominance of one or more of the above minerals, may show an orderly sequence.

From a petrographical examination of the rocks, one can frequently recognise progressive changes in the degree of metamorphism. These changes are most clearly demonstrated in those members of the schist group which contain the minerals kyanite and sillimanite. Kyanite and sillimanite are the index minerals for the highest grades of regional metamorphism of the pelitic type of sediments. Kyanite is formed characteristically under conditions of great pressure though not excessive temperature, and is a typical stress mineral (Harker, p. 150). Sillimanite is stable under conditions of great pressure and temperature and is indicative of the highest grade of metamorphism.

The kyanite crystals, where developed in the schists, invariably show diablastic or poikilo-blastic intergrowths with quartz. This suggests that the kyanite had only reached an early stage of crystalloblastic development as prolonged or more intense metamorphism would have permitted of the growth of idioblastic crystals more or less free from inclusions. Thus, very probably no portion of the area mapped was ever subjected to prolonged metamorphism of the highest grade. On the contrary, some types of schist contain assemblages of minerals, of which some are not in equilibrium, and whose presence indicates a lag effect during retrograde metamorphism. This retrogressive metamorphism is probably induced by cooling under diminished pressure either as the last phase of the primary regional metamorphism, or after some later period of heating.

Progressive metamorphism is clearly shown in types such as 15338 which consists of a matrix of recrystallised quartz with intercalated chlorite, which can be seen altering to biotite. Associated with the biotite are small staurolite grains and a little sillimanite. In type 15376 there is also abundant kyanite in small crystals showing diablastic structures.

Staurolite, indicative of an intermediate thermal stage is frequently missing in these rocks. Some specimens (*e.g.*, 15372) which have a strongly marked schistose structure, contain only diablastic kyanite developing from biotite, with no sillimanite. This indicates recrystallisation under conditions of great stress and only moderately high temperature.

Retrogressive metamorphism without stress is shown by types 15330 and 15379, where sillimanite, kyanite and biotite can be seen altering to chlorite. An example of retrograde metamorphism under stress is given by type 15674 in which sillimanite and biotite are altering to white mica, while fairly large anhedral crystals of kyanite, though mechanically fractured, have remained stable.

A very interesting example of the effect of lagging during retrograde metamorphism is to be seen in one specimen of a garnetiferous gneiss (15364), in which pink garnet, probably almandine, and biotite, are altering to chlorite which contains many inclusions of small, strong, freshly formed staurolite prismoids. Apparently the cycle of progressive thermal metamorphism had reached the stage of the development of staurolite, when retrogressive meta-

morphism was initiated with a decrease in the temperature. The garnet and biotite have responded to the new conditions, but the staurolite has failed to react.

The mineralogical composition of the gneisses and quartzites is such that they are far less responsive, than the schists, to changed conditions of temperature and pressure. The predominant textures in the "augen" gneiss and the "quartzites" are cataclastic, indicating rather intense stress under "epizone" conditions.

The principal rock type of the series, the biotite gneiss, has textures varying from granitic to granoblastic, in which recrystallisation has taken place under moderate temperature-pressure conditions, as shown by the development of fresh-looking crystalloblastic felspar rimmed by idiomorphic biotite laths.

A higher grade of metamorphism of this rock is shown by the replacement of the biotite by dark green diablastic hornblende, indicating an increase in stress. The appearance of garnet enclosing quartz and hornblende in a garnet-hornblende-gneiss marks the highest grade of metamorphism of this type of rock.

Mechanical deformation of the garnet, however, indicates a later shearing stress. This stress may have been responsible for the mylonitisation of the felspathic "quartzite" and the augen gneiss.

B.—*Origin.*

No reliable chemical analyses of any of the rocks of this area have as yet been made, and so criteria to be discussed in connection with the origin of the Chittering Series must be confined to those based on the field occurrence and on mineralogical characteristics.

(1) *The Schists.*—In the field the schists show rather rapid changes in composition across the strike which is characteristic of original sedimentary, rather than igneous rocks. Also the schists vary frequently in structure and composition along the strike. These changes are so rapid and marked that it seems reasonable to explain them as due to the co-operation of two factors —variation in the character of the original rock and variation in the degree of metamorphism.

In hand specimen the lenticular mica schist shows the structure typical of a highly sheared impure sandy conglomerate, traces of original rounded quartzitic pebbles being clearly visible and the whole appearance strongly suggests a sedimentary origin for this rock type.

The mineralogical composition of the sillimanite, kyanite, and staurolite bearing schists, and the garnet-chlorite-staurolite gniess is consistent with that of a metamorphosed pelitic sediment, probably an argillaceous sandstone (Tilley, C. E., 1926). A notable feature of these rocks is the presence of abundant dark, rounded zircons. These zircons have all the characteristics of detrital grains which have remained stable and unaltered throughout the different grades of metamorphism to which the rocks have been subjected.

Opinion as to the validity of the use of zircons in metamorphic rocks as a criterion of their origin, is at present divided. Trueman (1912) postulated that the presence of abundant well-rounded zircons was a fairly safe indicator of an original sedimentary rock. He is followed by Winchell (1924) and Harding (1931), who both use the presence of well rounded heavy minerals, including zircons, to conclude a sedimentary origin for certain metamorphic rocks. C. G. Carlson (1920) and P. Armstrong (1922), how-

ever, point out that during the shearing and resultant granulation of an igneous rock, any original zircons in it may acquire rounded edges, and they also give examples of the occurrence of well-rounded zircons in undoubted igneous rocks.

However, the abundance and the darkened and pitted appearance of the zircons in the above-mentioned rock types is not inconsistent with, but to the author's mind rather supports, the assumption of their sedimentary origin.

The basic hornblende schist grouped with the schists, differs markedly in composition, as has been shown, from the sheared epidiorites, which are probably much younger. The hornblende needles show pleochroic haloes about zircon grains, which is a common occurrence in the Chittering Series. The mineral composition provides no decisive evidence of their origin.

2. *The Gneisses.*—Biotite gneiss is abundantly distributed throughout the central portions of the area, but is by no means uniform in composition or structure. Basic bands are found grading into more acidic, and massive types into bands showing ptygmatic veinlets of quartz and pegmatite. Many outcrops remind one of descriptions of Sederholm's "migmatites" (1923 and 1926).

Fine-grained biotite gneiss may have textures ranging from granitic to markedly crystalloblastic in which clear plates of plagioclase felspar show small laths of biotite moulded around their margins. Some types of biotite gneiss carry rounded grains of zircon, similar to those found in many of the schists, enclosed in biotite. Probably the best explanation of the origin of this rock type is that it is part sedimentary, part igneous; that it consists of refused pelitic material which has been intimately penerated under Katazone conditions by acid magmatic solutions, and that the resulting plastic mass, after a certain amount of fluidal movement producing ptygmatic veins, has recrystallised as biotite gneiss.

The origin of these postulated magmatic solutions is unknown but the gneissic granite which is believed to be much younger than the "granitisation" period probably was not derived from the same source. The hornblendite granulites were possibly basic seggregations in this recrystallised material.

The hornblende gneiss and hornblende-garnet gneiss may be considered as genetically related to the biotite gneiss, representing progressively higher grades of dynamic and thermo dynamic metamorphism.

The augen gneiss in the west of the area shows a remarkably constant mineralogical composition throughout, but apart from the evidence of intense dynamic stress, the mineral structure furnishes little to indicate its origin. In the field, the gneiss is interbedded between two undoubted para-metamorphics which may suggest a sedimentary origin for this type (Cp. Jimperding Area).

Possibly this is an injection gneiss which originally formed an igneous sill or sheet. The sillimanite-mica schist on the western border of this gneiss may then represent a contact metamorphic zone.

3. *The "Quartzites."*—The field occurrence of the felspathic "quartzite" rather suggests some relation between it and the gneissic granite which in many places appears to form its eastern boundary. This "quartzite" shows evidence of strong dynamic stress which may have been caused by the intrusion of the granite.

The mineralogical composition of this "felspathic quartzite" is not inconsistent with that of an original impure sandstone (Turner, E. J., 1935, p. 412), but it may equally well represent original acid igneous material.

The "epidote quartzite" in field occurrence, structure, and composition, strongly suggests its para-metamorphic origin. The high content of lime shown by the presence and habit of the abundant epidote which occurs in crystalloblastic aggregates associated with a little poikiloblastic hornblende set in a recrystallised quartzitic matrix, indicates an original impure, rather calcareous, sandstone.

The quartzitic slate is undoubtedly a pelitic sediment which has undergone remarkably little metamorphism. This is abundantly clear from an examination of the micro structure. This rock, however, may yet prove to be a down-faulted relict of a much later series, though up to the present no convincing field evidence for this has been remarked.

For the fine grained quartzite, both field occurrence and the composition is consistent with that of pristine pure, fine-sand bands in the pelitic material now forming mica schists, gneisses and quartzitic slate.

V.—GEOLOGICAL HISTORY OF THE AREA.

Until the structure of the area which has been mapped, to date, in the Lower Chittering Valley, has been worked out, the age relations of the different metamorphics of the Chittering Series must remain in doubt and consequently no definite statement regarding the geological history of the area should be made. However, it may be as well to give a brief summary of the writer's opinions as to the history, acquired from a study of metamorphism.

As has been shown, the Chittering Series consists of a series of metamorphosed sediments, and possibly some acid igneous gneisses, which have been intruded by later acid and basic intrusives.

The bulk of the metamorphics probably originally consisted of a series of sandy shales interbedded with thin bands of sandstone, grit and conglomerates, and possibly a little calcareous mudstone. These sediments were probably laid down in early pre-Cambrian time (perhaps early Yilgarn) and in all likelihood a little earlier than the Jimperding Series.

These sediments were deeply buried and subjected to great temperatures and pressures which caused the beds to become strongly folded and partly fused. The result of these conditions was to produce predominantly highly schistose micaceous rocks containing the aluminous silicates, sillimanite and kyanite. Probably during the final stages in the development of these schists, or possibly in some later period, great quantities of very fluid acid igneous material, by some process of magmatic stoping, entered the sediments and penetrated many parts of them intimately. This "peaceful penetration" would be most easily effected in the weaker and more schistose micaceous bands. The action of these very siliceous, potash and soda-bearing solutions would be to convert aluminous silicates to mica, and to cause the crystallisation of quartz and the acid felspars now seen in the biotite gneisses.

Later, the area was intruded by undoubted igneous rocks. The first was a granite bathylith which entered the area from the east. This granitic magma which probably had an entirely different source from the "granitising" solutions mentioned above, and may have been concomitant with, or a part of, the great Darling Range bathylith, was very likely not accompanied by great heat and was followed by a pegmatite phase.

The final phase of igneous activity is represented by basic dyke rocks which intruded all the pre-existing rocks along swarms of fissures which ran in roughly north-south directions parallel to the axes of folding of the metamorphics. Many of these dykes acquired a schistose structure, either due to earth movements practically contemporaneous with the intrusion, or as the result of a later regional stress which followed a period of increased thermal action. This regional stress may have been responsible for many of the cataclastic structures now seen in some of the acid types of rock.

The area was then subjected to long continued erosion. There is no direct evidence of any later accumulation of extensive sedimentary series since pre-Cambrian times. A few miles to the south-west of the Lower Chittering area, the Bullsbrook leaf-bearing shales, which are believed to be of Jurassic age, are found overlying gneiss. It is quite possible that this series originally extended over the area under discussion and that later denudation has removed all trace of them, except perhaps, the remarkably unaltered quartzitic slate described above.

The superficial capping of the ubiquitous laterite or duricrust is considered (Woolnough, W. G.. 1918, p. 385) to belong to a recent period when a great part of W.A. had been reduced to a peneplain.

Since that time, the area has undergone further denudation and dissection by streams as has been outlined in an earlier section of this paper.

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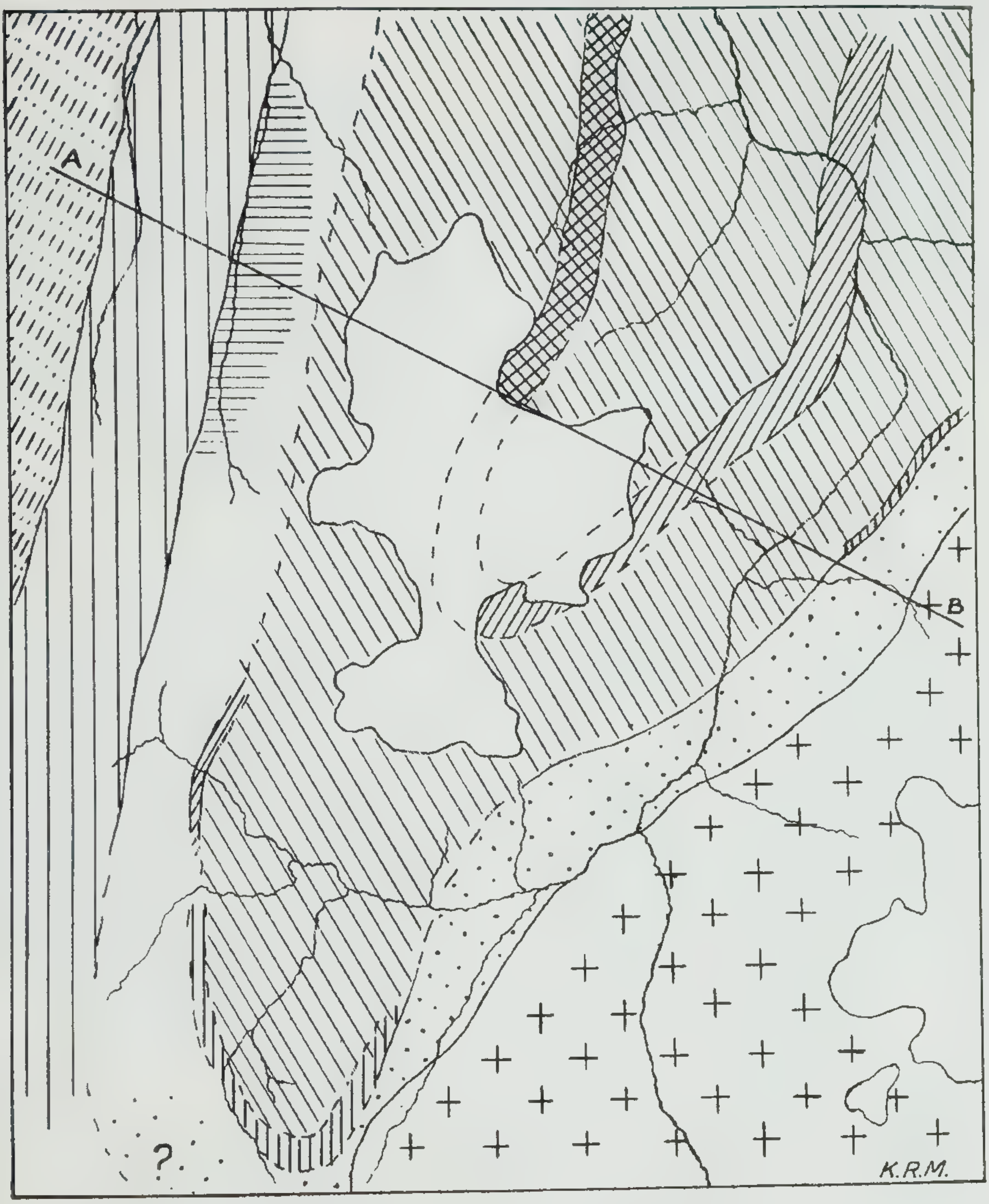
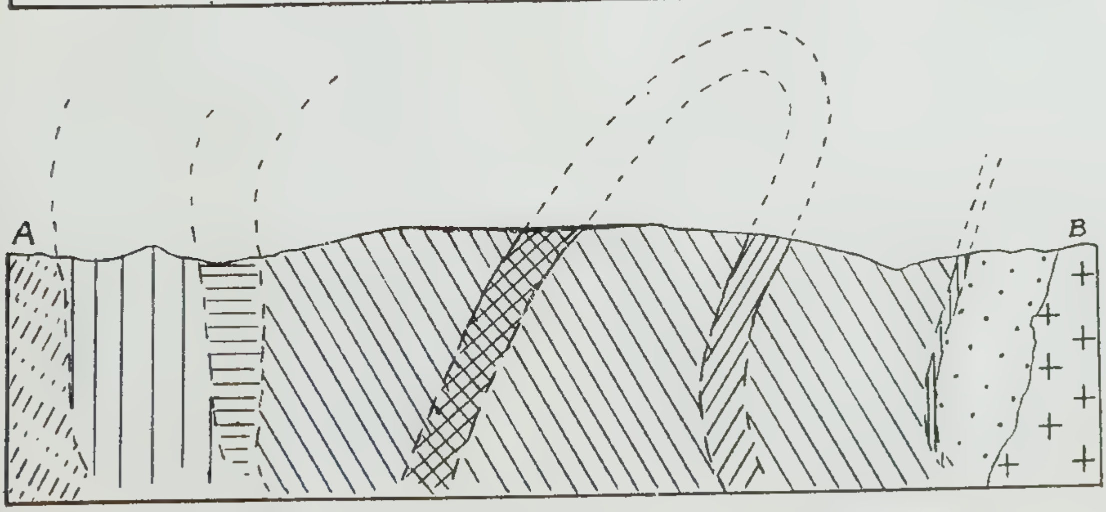




Idealised Plan and Section showing Suggested Structure of the Area. For Legend, see Geological Map.

EXPLANATION OF MICRO-PHOTOGRAPHS.

Fig. 1.—*Sillimanite-Kyanite Schist*—Spec. 15379, showing kyanite in a diablastic intergrowth with quartz, and sillimanite enclosed in chlorite.

Ordinary Light × 35.

Fig. 2.—*Kyanite-Sillimanite Gneiss*—Spec. 15385, showing sillimanite in coarse needles, and brushes of fine acicular needles; and associated biotite with pleochroic haloes about inclusions of zircon.

Ordinary Light × 34.

Fig. 3.—*Kyanite Schist*—Spec. 15372, showing kyanite developing from biotite with diablastic inclusions of quartz and a rounded zircon.

Ordinary Light × 35.

Fig. 4.—*Garnet-Chlorite-Staurolite Gneiss*—Spec. 15364, showing portions of garnet crystals, partly surrounded by, and altering to chlorite. A few small prisms of staurolite are scattered through the chlorite. The colourless mineral is quartz.

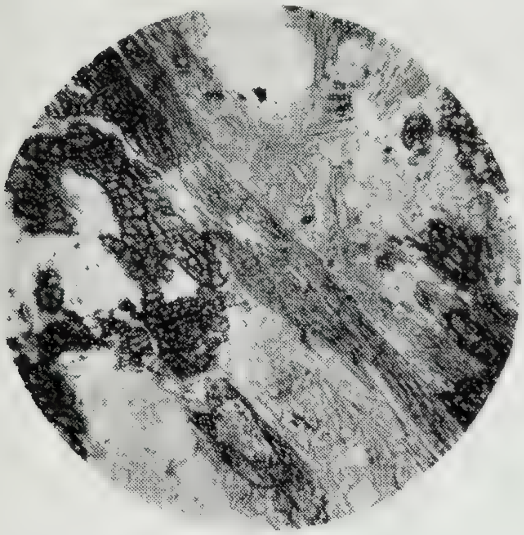
Ordinary Light × 34.

Fig. 5.—*Felspathic "Quartzite"*—Spec. 15349, showing a cracked and slip-faulted crystal of oligoclase in a cataclastic matrix of quartz and felspar with a little epidote.

Crossed. Nicols × 35.

Fig. 6.—*Biotite Gneiss*—Spec. 1518, showing biotite laths arranged round the periphery of a plagioclase crystal.

Ordinary Light × 35.



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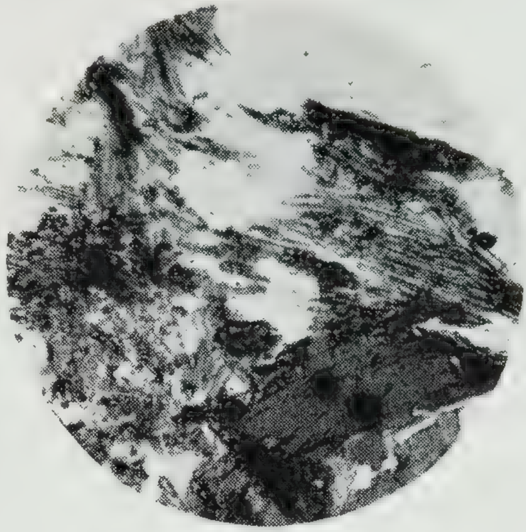

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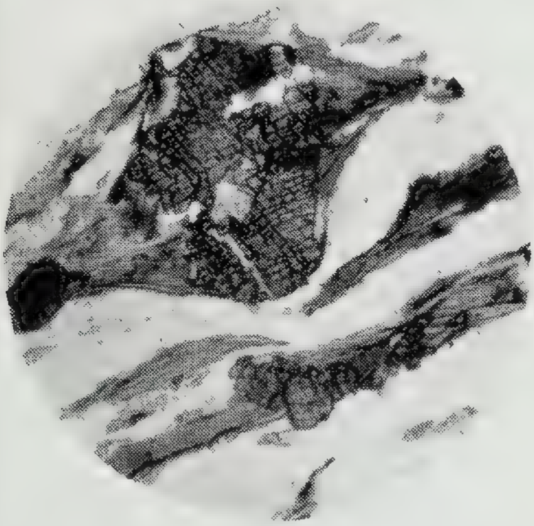

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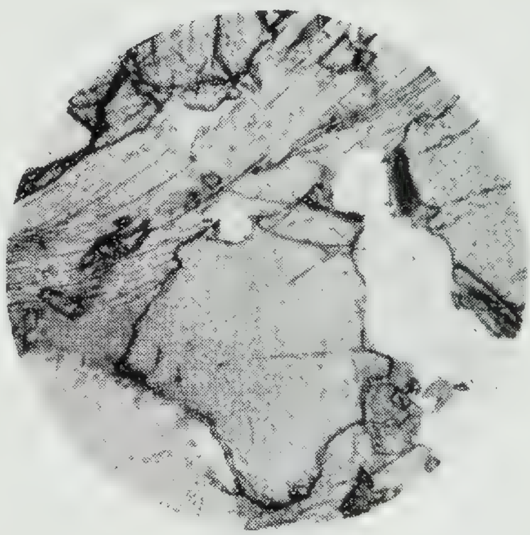

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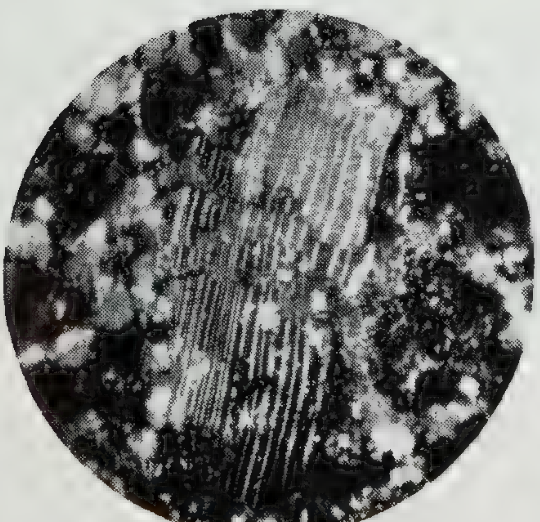

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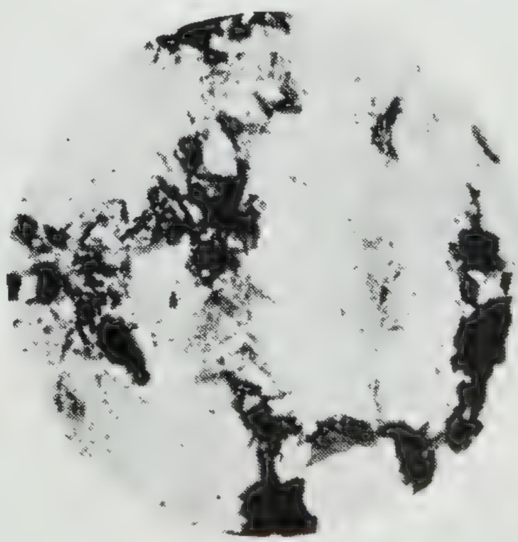


6

MICROPHOTOGRAPHS.


GEOLOGICAL MAP
OF THE
LOWER CHITTERING AREA.
Geological Boundaries
Location Lines
852
Form Lines
Strike & Dip
75°
Houses
Scale of Chains
Trig Station
LEGEND
Alluvium
Laterite
Dolerite
Hornblende Schist (Sheared Epidiorite)
Gneissic Granite
Pegmatite
Mica Schist (With Sillimanite)
Augen Gneiss
Quartzitic Slate
Biotite Gneiss
Hornblende & Garnet-H'blde Gneiss
Mica Schist (Ferruginous)
Mica Schist (Lenticular)
Felspathic Quartzite
Epidote Quartzite
Sillimanite & Kyanite Schists
LOCALITY PLAN
LOWER CHITTERING AREA
PERTH
To Perth
North Brook
To Lower Chittering
Plunkett's Gully
To Plunkett's Saw Mill
Camp Creek
Wilson's Creek
Convict Creek
Prospect Creek
Chittering Brook
Banksia Gully
Marda Brook
No 3 Creek
No 2 Creek
No 1 Creek
Geology Obscured
M 864
M 867
M 866
M 901
M 874
M 865
M 106
M 862
M 863
826
852
1260
1346
1306
1225
882
1398
1305
1330
1331
1399
WT
K.R.M.

[illegible]

3.—WEST AUSTRALIAN MYDAIDAE (*DIPTERA*).*

By KENNETH R. NORRIS.

Read 10th August, 1937. Published 6th April, 1938.

CONTENTS.

The Australian species of the family *Mydaidae* were treated by Hardy (*Proc. Linn. Soc., N.S.W.*, 1925, page 140), and corrections and new species were subsequently added by I. M. Mackerras (*Proc. Linn. Soc., N.S.W.*, 1928, page 539). The latter paper also contains a very useful key to the species. The purpose of the present paper is to provide additional notes on the Western Australian forms, adding one new species.

The writer is indebted to Mr. L. Glauert, Curator of Perth Museum, and to Mr. L. J. Newman, Government Entomologist, W.A., for the loan of some of the material studied. His thanks are also due to Dr. I. M. Mackerras, and to Mr. K. E. W. Salter, of the Macleay Museum, for help in comparing material.

Wing-venation.—Tillyard (Insects of Australia and New Zealand, 1926) labels the vein arising from the median cell of *Miltinus* as M1 + 2, assuming that the single vein represents a coalescence of the first and second median veins. This is one of two possible assumptions that can be made as to the correct notation of the vein in this genus. The other possibility is that the first median vein only is represented, the second having disappeared in the wing-membrane separately from M1.

That the latter view is more likely to be correct was suggested by an examination of the wings of a series of specimens of both sexes of *Miltinus minutus* Mackerras, captured near Fremantle. Six of the twenty-eight specimens in this series have a vestige of M2 arising from the base of M1 (Plate 1, Fig. A). There cannot be much doubt that this is an atavistic character in these specimens. The existence of a stump of M2 in such a position indicates that the vein in question disappeared separately in the wing-membrane and that the remaining vein is more correctly to be labelled M1 than M1 + 2.

Some specimens of this and other species show a distinct tendency for M1 to become very thin, indicating that this vein may be tending to undergo obliteration as M2 has done.

*Submitted as a supporting thesis for the degree of Master of Science at the University of W.A. The author wishes to acknowledge his indebtedness to the University of Western Australia for the grant of a Hackett Studentship, during the tenure of which this paper was written.

Specific Characters.—Descriptions based on colour alone may cause considerable trouble, owing to the fact that *Mydaidae*, especially the females, are very apt to become greasy after some time in collections. Mackerras pointed out the value of the proportions of the antennal segments in taxonomy, this character being of considerable value in the grouping of species, but of little use within the groups so formed.

The male terminalia of most of the species examined in this paper are recognisably different from one another, but the distinctions are difficult to illustrate or describe accurately.

Key to Genera of Australian Mydaidae.

Veins M1 and M2 both present in Wing—*Diochlistus* Gerstaecker;
M1 alone present in Wing— *Miltinus* Gerstaecker.

Diochlistus mitis, Gerstaecker.

1 male, Canning Bridge, W.A., November, O'Connor.
1 male, Gnangara, W.A., November, Perry.
10 males, 4 females, Applecross, W.A., September and October, 1934, K. R. Norris.

The specimens collected by the writer were taken flying around in open jarrah forest country, often resting on bare sandy patches. The species was quite common in the locality.

Miltinus stenogaster, Westwood.

1 male, Cunderdin, W.A.
1 male, Cottesloe, W.A.
1 male, January, 1 female, December, Swan River, W.A., L. J. Newman.
1 female, Gnangara, W.A., November, O'Connor.
6 males, 2 females, Fremantle, W.A., November, 1934, K. R. Norris.

This species is fairly commonly taken resting on sandy patches of ground in the Fremantle district, even on vacant allotments in the town.

One specimen in the Perth Museum collection is mounted on the same pin as a species of *Mantispidae* to indicate that the fly was taken with the lacewing as prey.

Miltinus musgravei, Mackerras.

7 males, 3 females, Rottnest Island, W.A., L. Glauert.
2 males, Rottnest Island, W.A., March, D. Swan.
1 male, Naval Base (near Fremantle), December, L. J. Newman.
1 female, Swan River, W.A., December, L. J. Newman.

n the female, which is rather more different from the male than described by Mackerras, there are only three pairs of creamy white spots on the abdominal terga, situated on tergites 2-4, whilst segments 5-7 lack them. These three apical segments are mostly brown, but the fifth tergite, and to a lesser degree the sixth, is blackish posteriorly and laterally. Tergites 2-4 have each a pair of inwardly-pointing, light brown wedges anterior to and lateral to the paired creamy spots.

Mr. L. Glauert has during the past few years collected a series of this species on Rottnest Island, where the flies occur in summer visiting flowering teatree. Mr. Glauert states that the female in flight carries the abdomen bent downward at the tip, and strongly resembles a male Thynnid wasp

carrying the female, the brown colouring of the apex of the abdomen heightening the resemblance. Such a species of wasp occurs on the island at the same season as the flies.

Miltinus maculpennis, Westwood.

1 male, Kelmscott, W.A., 1st January, 1936, K. R. Norris.

1 pair taken in copula, Crawley, W.A., 28th December, 1935, K. R. Norris.

The male from Kelmscott was secured on an open sandy block of ground with sparse vegetation. The pair taken in copula was flying around in long grass in the grounds of the Biology Department of the University at Crawley.

The extent of the black colouration at the tip of the abdomen differs in the two male specimens. In one case the fifth tergite has a transverse black band near the anterior edge, whilst the sixth tergite has a narrow orange band along the posterior edge. The other specimen has the fifth tergite almost completely orange, except for a narrow central black stripe, whilst tergite 6 is completely black. Tergites 2-5 have each a central black mark which shows some variation in the extent of its development. The female specimen has tergites 5-7 of the abdomen completely black.

Miltinus minutus, Mackerras (Plate 1A).

1 female, Garden Island, W.A., 23rd February, 1935, K. R. Norris.

12 females, 15 males, Applecross (near Fremantle), W.A., January, February, 1935-36-37, K. R. Norris.

This species is frequently to be taken perching on bare sandy patches, like other *Mydaidae*, but has also been captured on several occasions whilst visiting the flowers of pink myrtle, *Hypocalymma robusta*.

The series studied shows an interesting range of variation.

The males vary widely in the stoutness of the build of the body. A specimen 12mm. in length is much more slender in thorax and abdomen than another specimen 10mm. in length from the same locality. The terminalia of the stout specimen are larger and more bulbous than those of the slenderer forms and differ in the shape of the forceps, these being much longer in the slenderer forms. The hind femora in the short, stout male are strongly incrassate. The tibiae are markedly curved, and carinate on the surface fitting against the femur, and with a strong apical tooth. In the slenderer specimens the hind femora vary to a form showing very little thickening, the tibiae being not so strongly curved, only slightly carinate, and with the apical tooth not so pronounced.

In the stout specimens the head is noticeably larger in proportion to the size of the body, and the labella of the proboscis are larger.

The females show a parallel variation in head characters, body stoutness, and condition of hind legs. There is also a wide variation in the degree of infuscation of the wings. Whereas some specimens are quite heavily marked with brown (fading out posteriorly and distally), there is a distinct gradation to forms in which the wings are almost as clear as in the male.

Differences in wing-venation have been dealt with in another section.

The variations described above show a gradation to the condition of the various structures of *Miltinus mackerrasi* sp. nov., to which this species was at first thought to be closely related, though it is now considered that the resemblance is purely superficial.

Miltinus, sp. (?).

A much damaged specimen from the collection of the Perth Museum belongs apparently to an undescribed species placed in the section of genus *Miltinus* separated by Mackerras by the fact of the third segment of the antennae being little more than twice the length of the first two together. The wings are clear. Antennae, legs, thorax and base of abdomen orange; terminal five segments of abdomen mostly brown.

The specimen is a female from Dumbleyung, W.A., and the material is insufficient for the preparation of a formal description.

Miltinus mackerrasi sp. nov. (Plate 1, B-F).

A very small slender blackish species with hyaline wings in both sexes, unthickened hind femora, and very short proboscis.

Measurement.—Male: Body (excl. head) 10mm., wing 6mm. Female: Body 12.5mm., wing 7.5mm.

Male.—Head (Plate 1, C): Ground colour black. Head-capsule very concave posteriorly, where it is completely dusted with silvery shite. Bristles black near hinder margin of eyes, but white on rest of posterior aspect of head.

Ocellar tubercle black, bare and shining, flanked on either side by a black patch which separates the white dusting on the back of the head from the white pulverulence above antennal level laterally. Each of these black patches bears a tuft of erect, inwardly-directed brownish hairs.

Below ocellar tubercle is a prominent black bulge, bare and shining, on the lower edge of which the antennae are inserted. The space between the lateral edges of this bulge and the eye-margin has a dense whitish pulverulence, which fades out towards the antennal bases. A tuft of very light brownish hairs flanks the antennae on either side.

The facial knob below antennae is shining black centrally, dusted with white laterally, and bears a dense moustache of hairs which are black centrally, changing in colour to brownish-white laterally.

Antennae dark brown. Proportions of segments (from base outwards) 14 : 7.3 : 30 : 40. Basal segment with a slight white dusting and a few blackish bristles. Second segment with a few shorter bristles. Terminal segment dilated, dark brown above, light yellowish-brown below.

Proboscis brown, very short and fleshy, not projecting beyond epistome. Labella very broad but flattened, comprising by far the greater part of proboscis. Palpi and maxillae very minute—usually only visible in preparations.

Thorax: slenderly built, ground colour very deep brown. With a complete faint dusting of silvery white.

Prothorax deeply constricted off from mesothorax and forming a long neck to the head which is extremely mobile.

Scutum with a faint, slender, median, white vitta fading out posteriorly. A pair of prominent white stripes flank this, broadening outwards anteriorly near the spiracular prominence. Lateral edges of scutum with a broad band of white dusting. The scutum has a coating of short brown hairs, most easily seen in greasy specimens.

Pleura for the most part bare, but with a few white hairs on prothorax. Sterna bare.

Wings (Plate 1B) hyaline. Veins dark brown. Anal cell open at margin. There are minor variations in wing-venation. The most important variation which occurs only in isolated specimens, is the formation of a small closed cell at the distal end of the median cell, by a brief fusion of veins M1+2 and M3+4 basad to the intermedian crossvein.

Legs dark brown. Hind femora not at all thickened. Hind tibiae straight.

Abdomen: Ground colour very dark brown. Anterior edge of each tergite with a complete transverse band of white dusting the width of which is equal to about one-fifth of the length of the tergite. This dusting, like most of the other white markings is only visible when the insect is viewed from certain angles. Eighth tergite a very narrow transverse strip, concealed beneath seventh.

Terminalia: (Plate 1D). The terminalia of the male are quite small and both pairs of forceps, particularly the lower, point upwards. Upper forceps with the blades very broad basally, strongly incurved and tapering at the tips where each bears a tuft of two or three truncated peg-like black spines (visible in preparations). Lower forceps paler in colour and with an abruptly tapered piece apically. Aedeagus simple, upwardly curved. Eighth sternite and forceps with short black bristles.

Female: Differs from male in being larger and in having a stouter abdomen.

Proportions of head-capsule taking head-width as standard:—

	Male (average of 5 specimens).	Female (average of 5 specimens).
Head width	100	100
Head height	67·5	70·5
Head length	50·5	47·5
Separation of eyes	32·5	36
Antenna length	61	66·5
Proboscis length	27	29·5

Variations: The variation in the series studied is very small. There are minor differences in the shapes of the cells in the wings and the vestiture of the vertex varies a little in colour.

Types: The type specimens will be placed in the Perth Museum.

Affinities: None of the described species appears to be closely related to this form.

Biological and Ecological Notes:-

The species is common from January to March about the Biology Buildings of the University at Crawley, and odd females have been collected south of Fremantle, and at Applecross, a few miles east of Fremantle.

On hot, still days dozens of specimens may be seen in the grounds of the Biology Buildings, where the males frequent the sunlit walls, tree-trunks, picket fences, and even the top of a packing case standing in the open. Curiously enough the males are seldom seen upon the ground, the usual habitat for Mydaids. Females are evidently much fewer in numbers than males, and usually inhabit the ground.

When the temperature is high the males are very active and may be seen hovering rapidly up and down the surface of tree trunks and walls. Every newcomer to a favourable situation is immediately investigated by the flies already there, and many cases have been observed of males attempting to pair with other males. Pairing takes places quite readily in captivity.

No evidence has been secured as to feeding habits. The mouth parts are never smeared with pollen as is often the case with *Apioceridae*. Dissected specimens have been found with colourless transparent fluid filling the food reservoir.

Occasionally specimens fall victims to the small jumping spiders which frequent the walls.

A curious feature of the external anatomy of this species is that the dorsal surface of the neck-membrane protrudes as a small, reddish vesicle. This can sometimes be seen to pulsate actively when the insect is given warmth and light, and as the movements are synchronised with the respiratory movements of the abdomen, presumably the sac contains a diverticulum of the respiratory system. The pulsation is very rapid but does not occur continuously. Other Mydaid species examined have a similar bulge in the dorsal neck membrane.

The abundance of material available has made it possible to conduct an investigation into the internal anatomy, on which the writer hopes to publish some notes in a subsequent paper.

The species is named in honour of Dr. I. M. Mackerras.

Note on Life History: Early in February 1936 a male and female were placed together in a glass vessel and were observed to pair several times. After an interval of about two days the female laid three eggs, which were rather football-shaped and dull yellow in colour (1.34mm. x 0.52mm.). A fortnight later these eggs hatched, disclosing three slender shining white larvae, one of which was preserved. The other two were placed in a petri-dish with sand and some wood debris. Some days later only one larva could be recovered, indicating a possible case of cannibalism.

A week after hatching the remaining larva was seen to be undergoing ecdysis, the process taking several days before completion.

The larva was given a broken egg of a phasmid (*Podacanthus sp.*) to feed upon, and was seen to bury its head in the yolk, which was later visible filling the alimentary canal. Unfortunately the larva did not survive until the third instar, the diet provided no doubt proving unsuitable.

First instar larva: (Plate 1 fig. E). Length 2.5mm. Differs from second instar chiefly in character of head capsule, which is larger in proportion to the body, different in shape and less strongly sclerotised.

Second instar larva: (Plate 1 fig. F). Length 3.3mm. Shining and creamy white in colour. Body roughly cylindrical, but rather flattened ventrally.

Head capsule with a few weak bristles. Details of mouthparts unfortunately not determinable.

Thoracic segments each bearing a pair of slender bristles ventrally. The abdominal segments bear laterally a slightly projecting flange, which rather breaks the cylindrical contour of the body. This flange is divided up into three slight lobes in each segment.

Body segments 5-9 each have a transverse row of four small pseudopods near the anterior edge of the ventral surface.

Terminal segment roughly conical, smoothly rounded apically, flattened ventrally. This segment has a very few weak bristles and bears the anus on the ventral surface.

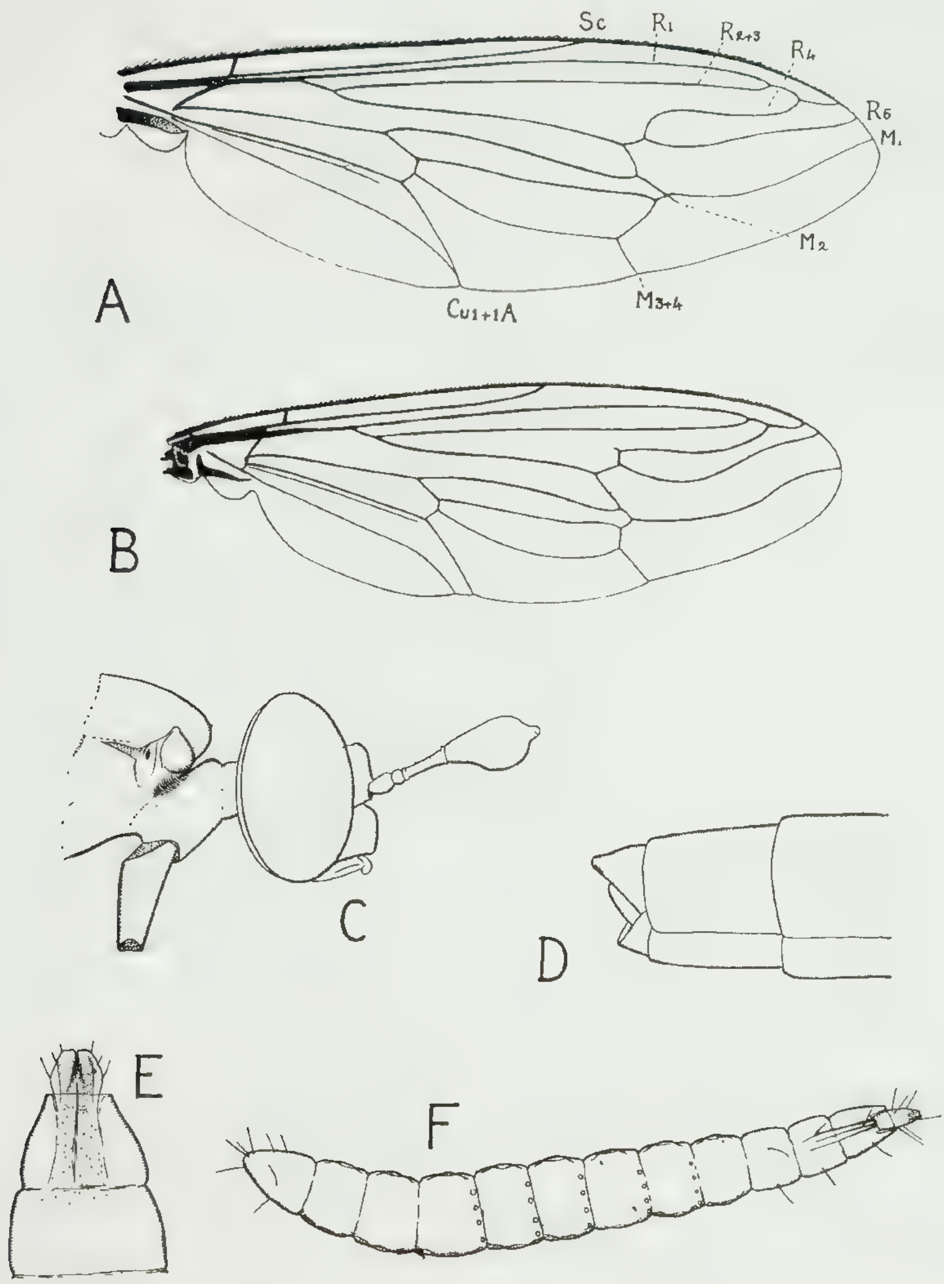


PLATE I.

A. Wing of **Miltinus minutus** Mackerras.

Figs. B–F. **Miltinus mackerrasi** sp. nov.

B. Wing.

C. Head and Prothorax.

D. Male terminalia.

E. Head and first two segments of 1st instar larva.

F. Second instar larva.

4.—*PALAEMONETES AUSTRALIS* DAKIN IN SOUTH-WESTERN AUSTRALIA.

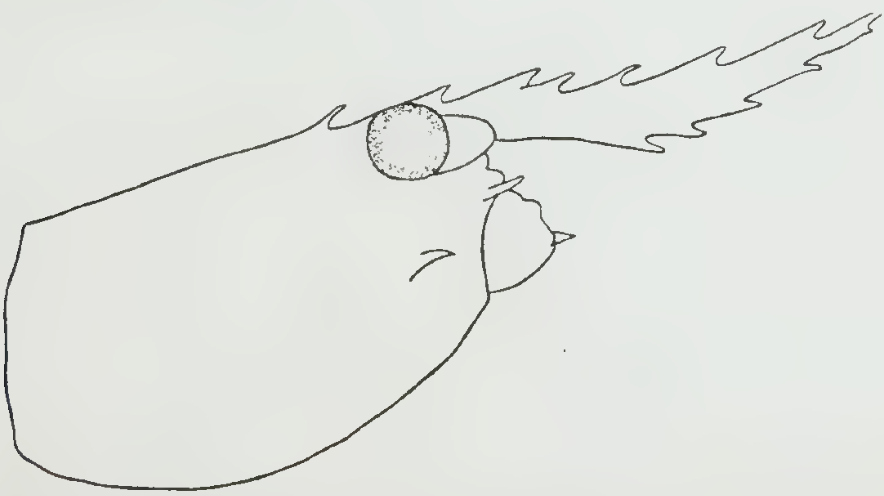
By D. L. SERVENTY,

Department of Biology, University of Western Australia.

Read 10th August, 1937. Published 6th April, 1938.

Recently I had occasion to examine a collection of Palaemonid shrimps from the estuaries, brackish lakes and freshwater swamps at Two People Bay, near Albany, with the endeavour of determining how far the freshwater *Palaemonetes australis* Dakin ranged into brackish-water, and, on the other hand, to what extent the marine *Leander* forms intruded into freshwater. I was not a little surprised to find out that all of the specimens I had before me belonged to one species, and that *Palaemonetes australis,* which has hitherto been regarded as exclusively fresh-water, flourished not only in the brackish lakes on the plain near Albany but was the species to which the excessively abundant shrimps of the estuaries belonged.

Estuarine, river, lake and swamp shrimps were thereupon examined from as many localities in South-Western Australia as possible, including the collections of the Western Australian Museum, and confirmation was obtained of the fact that only one species was represented in all these varied environments. This was the case also in the estuary of the Swan River, where the salt- and brackish-water shrimps had long gone under the name, locally, of *Leander intermedius* Stimpson.



Palaemonetes australis, ♀ Swan River estuary, 33 mm. long; cephalo-thorax showing positions of antennal and branchiostegal spines. x6.

In every case, however, dissection showed that the mandible lacked a palp and that, therefore, the animals were members of the genus *Palaemonetes.* Externally these shrimps so resemble *Leander intermedius* that confusion between the two is readily understandable. The resemblance extends to the position of the branchiostegal spine, which in both forms is set far back from the edge of the carapace and does not overlap its front edge. Prof. W. J. Dakin in his description of the species (1915, p. 571) did

not discuss the position of the spine, which at the time he wrote was not considered as variable in this genus. Later S. Kemp (1925, p. 318) described *Palaemonetes hornelli* from South India, which he thought was probably unique in the genus in possessing a branchiostegal spine which was set far back from the carapace margin. As has been stated, *Palaemonetes australis* also proves to possess this character and hence its position in Kemp's artificial key to the genus (*l.c.*, p. 315) is incorrect. The species is otherwise quite distinct from *P. hornelli* and differs from it, for instance, in the smaller number of dorsal teeth on the rostrum, the proportions of the fused and free portions of the outer antennular flagellum and the proportionate lengths of the segments of the second leg. *Palaemonetes australis* also differs in lacking an appendix interna on the first pleopod of the male, conforming in this respect with all the members of the genus other than *P. hornelli.*

The following details of the structure and habits of *Palaemonetes australis* supplement Dakin's account, whose diagnosis covers, in general, the typical features of the species.

Colour.—The animal is translucent, with a slight brownish green tinge. Minute chestnut-brown chromatophores, centred with black, are scattered uniformly over the whole body, including the eye-stalks, peduncles of the antennule and antenna, the squame, rostrum and legs. The spots are aggregated into more distinct lines transversely on each abdominal sclerite near its posterior margin, excepting the last two and the telson. On the rostrum occur two longitudinal, sub-marginal rows of pigment spots, and on the carapace there run one longitudinal and one oblique line of spots, with transverse "offsets." The chela of the second leg has no distinctive colour, such as affords a useful diganostic feature in discriminating between species of the allied genus *Leander*.

Variation in Rostral Teeth.—As with the European *Palaemonetes varians* (Leach) there is considerable variation in the number of teeth on the rostrum, and also, as in that species, there seems to be no correlation between the number of teeth and the nature of the environment.

Specimens from the Swan River estuary (marine conditions in summer, diluted in winter) show the following rostral formula (the small tooth forming the bifid tip of the rostrum being included in the count of the dorsal teeth) :—

Dorsal teeth	5	6	7	8	9
Number of Specimens	1	1	18	5	2

Ventral teeth	2	3	4
Number of specimens	2	21	4

Combinations	7/3	8/3	7/4	9/3	6/3	9/4	8/4	5/3	8/2
Number of Specimens	15	3	2	1	1	1	1	1	1

Specimens from King Creek Lagoon (salt) near Two People Bay, Albany, had the following formula :—

Dorsal teeth	5	6	7	8	9
Specimens	2	14	3	0	0

Ventral teeth	2	3	4
Specimens	0	18	1

Combinations	6/3	7/3	5/3	7/4
Specimens	14	2	2	1

Shenton Park Lake, Subiaco, specimens (fresh-water) showed the following variations:—

Dorsal teeth	5	6	7	8	9	
Specimens	1	9	13	1	0	
Ventral teeth	2	3	4			
Specimens	0	16	8			
Combinations	7/3	6/3	7/4	6/4	8/3	5/3
Specimens	7	7	6	2	1	1

Lake Seppings, Albany (fresh-water):—

Dorsal teeth	5	6	7	8	9
Specimens	0	3	3	0	0
Ventral teeth	2	3	4		
Specimens	1	6	0		
Combinations	6/3	7/3	7/2		
Specimens	3	2	1		

Canning River at Gosnells (fresh-water):—

Dorsal teeth	5	6	7	8	9
Specimens	0	1	6	1	0
Ventral teeth	2	3	4	5	
Specimens	0	4	3	1	
Combinations	7/3	7/4	7/5	8/4	6/3
Specimens	3	2	1	1	1

Several specimens from all localities lacked the bifid extremity to the rostrum, while in other cases a supplementary small tooth formed a trifid tip. An abnormal specimen from the Canning River, Gosnells, showed the formula of 10/5, a fracture near the tip of the rostrum having resulted in regeneration of the extremity with additional teeth.

These formulae tend to show that rather a different average prevails in different areas, supporting Gurney's view (1923, p. 115) in his review of the variation of the rostral teeth of *R. varians*, that a statistical study of the variations of the rostral teeth based on a large amount of material "would show constant local variations, since many populations of this species must be isolated for long periods and subject to intense selection."

Second Leg. In the second leg the carpus is longer than the propod and the merus, but the proportions vary. The dactylus is 40-45% of the total length of the propod, the chela being quite slender. The merus is generally slightly less than the propod in length, though in some cases these two segments are equal. All individuals differ in the proportionate lengths of the second leg segments from the otherwise externally closely similar *Leander intermedius*. In the latter species the propod exceeds the carpus in length, the merus is considerably shorter than the propod and the dactylus is 50% of the length of the propod. (See table.)

Outer Antennular Flagellum.—The free portion of the outer antennular flagellum varies from equality with the fused portion to being twice its length, and this variation seems to have no correlation with environment or sex. Many Swan River estuary specimens have the free portion of the same length as the fused part, which is the condition which Dakin describes from his type material from the Avon River at Northam.

The following table gives the proportions, in a number of individuals from various localities, of the lengths of the second leg segments and the ratios of the parts of the outer antennular flagellum. The measurements are expressed as percentages of the carpus and the fused part of the flagellum, respectively.

	Length.	Second Leg.				Outer antennular Flagellum.	
		Dactylus.	Propod.	Carpus.	Merus.	Fused part.	Free part.
Leander intermedius.							
	mm.						
Garden Is.	34	60	123	100	88	100	226
Do.	35	56	118	100	78	...	...
Palaemonetes australis.							
Swan River estuary ...	34	42	98	100	70	100	88
Do. do. ...	32	37	84	100	67	100	100
Do. do. ...	31	33	79	100	69	100	175
♂ Do. do. ...	33	48	89	100	69	100	137
♂ Lake Gardner, Two People Bay (Brackish)	27	34	78	100	75	100	214
♀ Do. do.	26	31	74	100	66	100	100
♀ Creek into Princess Royal Harbour (Salt)	30	26	70	100	66	100	139
Canning River, Gosnells (Fresh)	38	30	76	100	74	100	200
Monger's Lake (Fresh)	...	28	63	100	65	100	88
Do. do.	...	...	...	...	...	100	106

Differences between Brackish and Fresh-water Populations.—In *Palaemonetes varians* the brackish-water and fresh-water forms are regarded as being structurally indistinguishable, but physiological varieties have been described on differences in reproductive habit (differences in size of eggs laid and the stage of development on hatching). Gurney (*l.c.*, p. 122) has further found that fresh-water examples of the species from Tunisia differ from the brackish-water representatives in the inordinate length of the appendix masculina of the second pleopod of the male and also the ratio of the free part of the outer antennular flagellum to the fused part. In *Palaemonetes australis* the appendix masculina does not vary in length whatever the environment, being intermediate in length between the appendix interna and the endopodite. The other variable features cannot at present be correlated with environmental differences.

Distribution and Occurrence.—The genus *Palaemonetes*, though very widespread in its distribution, has been recorded from Australia only in the south-west corner, and here the species has been collected from Two People Bay on the south-east coast to the Gingin Brook, north of Perth. Within this area the animals occur in streams, from the fresh upstream reaches to their brackish-water mouths and estuaries, in many of the brackish-water lakes of the coastal plain which appear to be isolated marine basins (such as Lake

Clifton and the lakes near Two People Bay), and entirely fresh-water lakes and swamps. As far as the estuarine and lacustrine distribution is concerned this is closely paralleled by the Goby, *Glossogobius suppositus* Sauv. (syn. *G. vomer* Whitley, *Rec. Austr. Mus.*, vol. xvii., 1929, p. 135). Neither *palaemon* nor *Atyid* shrimps occur in South-Western Australia, whose place in the fresh-waters is taken by *Palaemonetes australis.*

In the Swan River estuary *Palaemonetes australis* is very abundant throughout, but in the harbour at Fremantle it is replaced by the marine form, *Leander serenus* (Heller), which is the common shore form around the South-West. *Leander intermedius* has not thus far been taken in the estuary but has been dredged in Cockburn Sound.

Experiments on varying the Salt Concentration of the Outer Medium.—The distribution of *Palaemonetes australis* as indicated is evidence that the species is a euryhaline animal with a wide degree of tolerance of the salt concentration of the medium in which it lives. In the Swan River estuary the animals are able to withstand very great fluctuations of the salinity during the year. In the summer and autumn and early winter the animals live in undiluted sea-water, and in the late winter and spring the flood waters come down and the fresh water extends to a depth of six or eight feet with brackish-water beneath, and the shrimps continue to live at all levels. There are very slight changes in the main estuary due to the tide, as the daily rise and fall is about eighteen inches or so, and this is quite overshadowed by the effects of the winds. Therefore the violent daily fluctuations in salinity, which are the order in European estuaries for instance, have no counterpart in local waters. The seasonal variations in salinity are relatively gradual and the osmo-regulatory equipment of *Palaemonetes* is evidently adequate to accommodate itself to them.

Experiments made to test the reactions of the animals to fluctuations of salinity showed, however, that *rapid* alterations of the concentration of salts, over a wide range, broke down the osmo-regulatory mechanism of the animals, and they succumbed. Gradual, but not unduly slow, alterations of the medium succeeded in transferring brackish-living shrimps quite safely to fresh-water and vice versa. Details of some of these experiments follow.

1. On May 14, 1936, 11 specimens brought from Monger's Lake (fresh) were placed suddenly (after the temperatures had evened) into undiluted water from the Swan River estuary (Chlorine, 19.8 per mille). Next day though only two were dead, all the survivors were very lethargic and had acquired an opaque whitish appearance. They never recovered; one or two died each succeeding day and the last survived to May, 26.

2. On the same day 15 specimens from Shenton Park Lake, Subiaco, (fresh) were placed in diluted estuary water (Chlorine 12.3 per mille). These remained normally active and transparent. Four days afterwards they were further transferred to undiluted estuary water (Chlorine, 19.8 per mille) but the transition proved too severe and the animals became sluggish and opaque, five dying within 24 hours, and the others succumbed one by one until none was left 15 days later. Never during this period did the lingering survivors show normal activity.

3. A third lot of specimens and two *Glossogobius suppositus* from the Swan River upper estuary at Guildford (Chlorine, 10.7 per mille) were

placed in fresh-water. The animals remained very active and transparent. One shrimp which survived a mishap in the aquarium, and the two gobies, were transferred a fortnight later into estuary water from Crawley (Chlorine, 18 per mille). All the animals were quite unaffected and the shrimp successfully underwent ecdysis.

4. A collection from the Swan River at Crawley (Chlorine, 18.55 per mille) was put into fresh water, but all died overnight, with the bodies greatly swollen. What probably happened, as in all these cases, was that the osmo-regulatory control had broken down under the strain of the too great change in the concentration of the outer medium, and water diffused into the body unimpeded, causing distension of the tissues and death. This experiment was performed at the same time as No. 3 and the contrast of the respective effects was striking.

5. An endeavour was now made to effect the transition from salt-water to fresh more gradually. On May 28 a catch of sixty shrimps was taken from the Swan River estuary (Chlorine, 18.55 per mille) and each day (with a few exceptions) the water was diluted. The following were the results:—

May 29—all active; the water was then diluted to Chlorine, 17.55 per mille.

May 30—all active; water was diluted to Chlorine, 10.85.

June 1—all active; water was diluted to Chlorine, 8.2; 5 hours later though all the animals remained alive they had become sluggish.

June 2—25 were found dead, being swollen and opaque, the remainder were active and transparent; the water was then diluted to Chlorine, 7.3.

June 4—all alive and active.

June 5 -ditto; water diluted further to Chlorine, 4.03.

June 6—all active. The specimens were now divided into two lots; one (A) consisting of 21 animals, was placed into fresh-water and the medium of the other (B) including 15 shrimps, was diluted to Chlorine, 3.38 per mille.

June 7—In A, 6 shrimps were dead, the remainder sluggish and not so active as usual though still transparent. In B the animals remained normally active and the water was further diluted to Chlorine, 2.60.

June 8—In A some shrimps resumed activity, other remained sluggish but there were no deaths. The animals in B continued normal and the water was diluted to Chlorine, 1.54.

June 9—In A animals alive but quiet; in B normal, water diluted to Chlorine, 1.01.

June 10—In A animals alive but quiet. In B normal; water diluted to Chlorine, 0.73.

June 11—In A 2 dead, others quiet. In B normal; water diluted to Chlorine, 0.38.

Palaemonetes in aquaria is very sensitive to the slightest contamination and it is the first animal to register discomfort when anything is wrong by attempting to leap out of the vessel.

Breeding Period.—Dakin considered that the breeding season coincided with the early months of the summer. The earliest time I have found ovigerous females was towards the end of August and the latest in January, no breeding taking place in the late summer or autumn. The breeding season seems identical in fresh-water and estuarine environments. It is interesting to note that in the Swan River estuary the effects of the winter flooding are near their maximum in August, yet this rigorous period has no effect, apparently, on the breeding.

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1915 Dakin, W. J., "Fauna of West Australia—iv. *Palaemonetes australis,* sp.n., being the first record of the genus in Australia," *Proc. Zool. Soc.* 1915, pp. 571-574.

1923 Gurney, R., "Some notes on *Leander longirostris* M. Edwards, and other British Prawns," *Proc. Zool. Soc.*, 1923, pp. 97-123.

1925 Kemp, S. "Notes on Crustacea Decapoda in the Indian Museum—xvii. On various Caridea," *Rec. Ind. Mus.*, vol xxvii, pp. 249-343.

5.—WESTERN AUSTRALIAN FORMS OF THE GIANT PETREL *MACRONECTES GIGANTEUS* (GMELIN).

By L. GLAUERT (1).

Read 12th October, 1937. Published 22nd March, 1938.

The Giant Petrel, *Macronectes giganteus* (Gmelin), is not at all rare in southern Australian waters at certain times of the year, particularly after winter gales, when, weak through lack of food, it is often brought ashore in a dead or dying condition.

The presence of the common or dark form off Western Australia has frequently been reported (2), but up to the present there is no evidence that the comparatively rare white phase with scattered blackish markings has ever been noticed on the western coast of the Continent. In fact it would seem that the only white specimen on the Australian list is the bird collected at Broken Bay, N.S.W., by E. A. Windle on the 4th September, 1914. This bird, formerly in the Gregory M. Mathews' collection, is now at Tring. (3).

It will therefore be of interest to report that on June 26th, 1937, the Western Australian Museum received from Mr. Sydney McGregor, of Busselton, a very fine specimen of this rare bird in excellent condition. In his letter the donor stated that he had picked it up on the beach near Busselton in Geographe Bay the day before.

The plumage of the bird, a male, is white with very sparse blackish markings on the head and body. These markings may consist of entirely black feathers, or of white feathers black at the tip, on one vane only or with blackish shaft streaks. The right wing is pure white, but on the left the two outer primaries are white, the third has a black mark on the outer vane near the tip, whilst the sixth is black apically for a distance of about nine inches. The tail is entirely white. White down is present on the head, neck and body.

When the bird arrived at the Museum its bill was ivory white with a strong pinkish suffusion, the iris reddish-brown and the feet blackish. The following measurements were taken:—Length 950 mm., wing 510, tarsus 90, bill (chord of the exposed culmen from the feathers on the forehead to the tip, measured with dividers) 90, depth near base 35, greatest width 29 mm.

The following particulars concerning local birds (dark phase) in the W.A. Museum may be of assistance to those workers desiring to solve the vexed question of geographical races.

(1) Communicated by permission of the Trustees.

(2) Campbell, A. J.—" Nests and Eggs of Australian Birds," 1901, pp. 909/910.
Basset Hull, A. F.—*Emu* Vol. XV., 1916, p. 215.
Alexander, W. B.—*Emu* Vol. XX., 1920, p. 66.
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Whitlock, F. L.—*Emu* Vol. XXVI., 1927, p. 156.
Glauert, L.—*Journ. Royal Soc W.A.*, Vol. XV. 1929, p. 39.
Whitlock, F. L.—*Emu* Vol. XXX., 1931, p. 264.
Do. *Emu* Vol. XXXVI., 1936, p. 14.
Serventy, D. L.—*Emu* Vol. XXXVII., 1937, p. 56.

(3) Lowe and Kinnear British Antarctic (Terra Nova) Expedition *Zoology*, Vol. IV., No. 5, 1930, p. 157.

Plumage (4).—The birds showed surprisingly little variation, there being an entire absence of the juvenile "shining black" in spite of the fact that the majority of the birds were immature. General colour between dark olive gray and deep neutral gray (Ridgway's colour standards) slightly paler—about a quarter tone—below. Feathers on neck and body with paler margins and becoming paler towards the base; down light gray. On the crown and cheeks basal portions of the feathers more brownish (warmer) on the throat; only the tips of the feathers have the general body colour, the rest being pale gray, almost white. With wear of the feathers the throat and chin become paler. All feathers examined have dark brown, almost black shafts, darkest towards the tip, paler basally.

In reflected light the darker tips and paler margins to the individual feathers produce a spotted or mottled appearance; this may be the "garb" characterised by brownish gray feathers with lighter gray margins of Murphy (5) and taken with the fact that there is a general absence of the white or gray head and neck, would seem to indicate that all the birds were approximately of the same age when collected.

A few slight variations were noticed. A 3761 from Wonnerup near Busselton has the plumage more brownish (warmer). In A 4823 from N. Fremantle it is on the whole more grayish (colder). On A 3302 from Cottesloe the chin and throat are paler (through wear of the feathers). A 3672 from Capel, near Busselton, on the other hand, has the chin feathers rather darker (perhaps a relic of the black juvenile plumage of Murphy). Three mounted specimens, which have been exposed to light for many years, show greater variation. C 281 from the Houtman's Abrolhos has the general plumage including the throat and chin more brownish, a feature slightly less accentuated in C 283 from Fremantle. C 282 from Bunbury has the chin and throat paler-whitish, though the general colour is normal.

Feet (*Colour*).—The colour of the feet as noted on the labels varies from slate (two), dark slate (one), to blackish (two) to black (eight); in the case of A 4650 the colour is given as "dark hazel." In the case of the three mounted specimens it is blackish.

Eye Colour.—The colour of the irides, where indicated, ranges from brown (five) to dark brown (four); gray, whitish or bluish gray or hazel are not represented though considered by Murphy (6) to be predominant. The Museum Taxidermist, who handled all the specimens, is of the opinion that in every case the bird had brown or dark brown eyes. It should be noted that in the early days of the Museum such data were not recorded.

Bill.—The colour of the bill has been noted in 12 cases. Of these six were "yellowish," one yellowish white, two horn colour, one ivory and two pinkish white, (A 2904, A 2905). The last two specimens are of importance as they show that the "ivory white with strong pinkish suffusion" of the white bird from Busselton is not an indication of albinism. In their present conditions the bills are yellowish ranging from ivory yellow to buff yellow.

Tables of measurements are appended.

(4) I am indebted to my colleague, Mr. G. Pitt Morison, the Curator of the Art Gallery, for assistance in the colour determination.

(5) "Murphy Oceanic Birds of South America," Vol. 1, p. 597 (1936).

(6) ib. loc. cit.: p. 585.

TABLE OF MEASUREMENTS.

Number.[1]	Date.	Locality.	Sex.	Bill. Length (1).	Bill. Depth (2).	Bill. Width.	Bill. Colour.	Wing (4).	Tarsus.
C 281	1894	Abrolhos	imm.	99	35·5	31·5	....	....	90 ?
C 282	1895	Bunbury	imm.	95	38	34	....	....	92 ?
C 283	1895	Fremantle	imm.	101·5	38	32·5	....	....	100 ?
A2862	?	?	imm.	88·5	34·5	29	....	495	89
6842	28-6-04	Busselton	?	102·5	40	29·5	....	515	97
A2751	9-7-25	N. Fremantle	male imm.	101	37	28	horn	525	94
A2904	8-7-27	Cottesloe	male imm.	85	32	28	pinkish-white	490	96
A2905	July 27	Cottesloe	female	95	39·5	28	pinkish-white	535	101
A3302	5-7-29	Cottesloe	male imm.	84	35	30	horn	510	89
A3667	7-7 30	Rockingham	imm.	95	38 (3)	29	yellowish	510	93
A3668	7-7-30	Scarborough	imm.	99	39	30·5	do.	530	94
A3669	9-7 30	City Beach	imm.	97	36·5	29·5	do.	520	95
A3672	15 7 30	Capel	imm.	97	40·5	31	do.	535	99·5
A3671	14 7 30	Wonnerup	female	101	40·5	29	do.	525	99
A4465	17 7-34	N. Fremantle	female	90	33·5	28	yellow	490	92
A4650	3 9 35	N. Fremantle	imm.	106	38·5	36	yellowish-white	532	102
A4823	26 5 37	N. Fremantle	female	82	32·5	27	ivory	500	95
A4837	26 6 37	Busselton	male	90	35	29	pinkish-ivory-white	510	90

(1) Chord of the exposed culmen. (2) Depth at base. (3) Bill slightly gaping.
(4) Where unequal, the longer is given.

	Maximum.	Minimum.	Average.
Bill—			
culmen	106	82	94·5
depth	40 5	32	37
width	36	27	30
Wing	535	490	515
Tarsus	102	89	95

ADDENDUM.

Falla, in B.A.N.Z. Antarctic Research Expedition, 1929-1931. Reports—Series B. Volume II. Birds, 20/8/37, which reached the Public Library in December, states on page 138: "The first juvenal plumage from all localities is very dark brown, almost black in its first gloss, with paler grey edging on the feathers of the nape and back producing a faint scaled pattern. Birds taken at sea in March were also in this plumage and all the winter specimens from the New Zealand coast are the same, some without the original gloss. Their immaturity is indicated by the condition of the gonads and the bones." The birds found on the New Zealand coasts in winter time seem to bear a close resemblance to those met with in South-Western Australia after winter storms.

6.—THE GENUS CORYSANTHES (ORCHIDACEÆ) IN AUSTRALIA AND NEW ZEALAND.

By H. M. R. RUPP.

Read 12th October, 1937. Published 6th April, 1938.

Communicated by G. R. W. MEADLY.

In Mrs. Emily Pelloe's admirable little book on West Australian orchids, I notice that she has admitted *Corysanthes pruinosa* Cunn. as the only representative of the genus found in Western Australia. With all due respect to the authority there cited, I venture to suggest that this is a mistake. In *Proc. Linn. Soc. of N.S.W.*, Vol. liii, part 2, 1928, there is an exhaustive review of the Australian species of *Corysanthes* by the present writer in collaboration with Mr. W. H. Nicholls, of Melbourne. We had not the opportunity of handling living specimens of the W.A. plant, but were able to examine carefully excellent dried specimens collected by Lieut.-Col. Goadby, in the Sydney and Melbourne National Herbaria. We both agreed that they could not be reconciled with either *C. pruinosa* Cunn. or *C. fimbriatta* R. Br. We were of opinion that they belong to a species described in our review under the name *C. dilatata* Rupp & Nich., though not quite typical (*Loc. cit.*, p. 85). Non-recognition of this quite distinct species had been the cause of much confusion in the Eastern States for many years. In Victoria it had been called *C. fimbriata*, and in Tasmania *C. pruinosa*. This probably formed the ground of Mrs. Pelloe's remark that these two species were doubtfully distinct. But in New South Wales, where both Brown's and Cunningham's types were found, there was no question of the specific distinction; and the Victorian *C. fimbriata* and Tasmanian *C. pruinosa*, between which Mr. Nicholls and I could find no difference, were not represented in New South Wales at all. On the other hand, we could discover no evidence of the existence of Cunningham's *C. pruinosa* outside New South Wales, with the possible exception of one very doubtful specimen from Queensland. But Brown's *C. fimbriata* reached us from Queensland, Victoria (where it had been overlooked), and Tasmania. It became quite clear that there was an undescribed species causing confusion; and with the establishment of *C. dilatata*, all the known Australian species are now plainly marked out. One (*C. undulata* Cunn.) had been completely lost sight of for 91 years; but was re-discovered by the writer at Bullahdelah, New South Wales, in 1923, and has since been collected on an island in Moreton Bay. The distribution of the various species, in accordance with the conclusions reached in our review, is as follows:—

C. fimbriata R. Br. ...	Q.	N.S.W.	Vic.	Tas.		
C.-diemenica Lindl.		N.S.W.*	Vic.	Tas.		
C. pruinosa Cunn.		N.S.W.				
C. dilatata Rupp & Nich. ...			Vic.	Tas.	S.A.	W.A.
C. undulata Cunn.	Q.	N.S.W.				
C. bicalcarata R. Br. ...	Q.	N.S.W.	Vic.	Tas.		
(Syn. *C. aconitiflorus* Salisb.)						
C. unguiculata R. Br. ...		N.S.W.	Vic.	Tas.	S.A.	

* Fitzgerald's unpublished *C. Hamiltonii* seems to us to be *C. diemenica*.

In my herbarium there are ten species of *Corysanthes* from New Zealand. Of these, only one is definitely identical with an Australian form: it can scarcely be doubted that Hooker's *C. Cheesemanii* is really, as Cheeseman himself suggested, Brown's *C. bicalcarata.* The majority of New Zealand species seem to be more nearly allied to those of New Guinea and other equatorial areas, than to those of Australia, being furnished with very long filamentose sepals and petals.

7.—THE ESSENTIAL OILS OF THE WESTERN AUSTRALIAN EUCALYPTS.

PART V.

THE OILS OF *E. ASTRINGENS*, MAIDEN, AND *E. PYRIFORMIS*, TURCZ.

BY G. E. MARSHALL AND E. M. WATSON.

Read 9th November, 1937; published 12th April, 1938.

EUCALYPTUS ASTRINGENS.

E. astringens, the brown mallet, is confined to the south-western portion of Western Australia, occurring in areas up to 100 acres in extent over country within the 12-inch to 25-inch rainfall belt. It extends from York to as far south as Cranbrook on the Great Southern Railway, westwards to Wandering and Arthur and eastwards to beyond Ravensthorpe.

The true wood of the tree varies in colour from light red-brown to a dark grey-brown; it has a fine and uniform texture and is very dense. Langlands (1937) has shown that the wood should be superior to that of the Queensland spotted gum (*E. maculata*) and karri (*E. diversicolor*) for such purposes as tool handles and that it should prove a satisfactory substitute for hickory for all but the most exacting purposes.

The bark is smooth, brown or bronze in colour and easily stripped from the tree throughout the greater part of the year. It varies in thickness from ¼-inch to ¾-inch, and it has a ready market on account of its high tannin content. The amount of bark stripped during the year July, 1936, to June, 1937, was 2,119 tons, of which 1,425 tons, valued at £14,491, was exported.

The leaves are shining, dark green in colour, lanceolate, and are freely dotted with oil glands. The veins are widely spaced and somewhat irregular; the marginal vein, which is well removed from the edge of the leaf, is indented to meet the lateral veins.

In view of the economic importance of the bark and of the valuable properties of the wood, additional interest attaches to the nature and possible uses of the oil.

The material used in this investigation was obtained through the courtesy of Mr. W. G. Chandler, B.Sc. (For.), Dip. For. (Canberra), of the Forests Department. It was collected during the flowering season, mid-October, in the vicinity of Narrogin, and its identity was verified by Mr. C. A. Gardner, Government Botanist.

The oil, which distilled rapidly, was pale greenish-yellow in colour, and had a pleasant, non-irritating smell. The yield was not high, varying from 0.5 to 0.6 per cent. calculated on air-dried material. The cineol content averaged nearly 50 per cent., and pinene was present in appreciable amount. The free acid and ester contents were small; alcohols, calculated as geraniol, made up little more than 8 per cent., and both low and high boiling aldehydes were present in small amount. The usual colour reactions for aromadendrene were given, and the oil slowly developed a purple colour when treated with ferric chloride. Phellandrene was absent. On distillation, insoluble material separated as boiling commenced; 81 per cent. of the oil was volatile below 195°, the rectified oil containing only little more than 60 per cent. of cineol. The oil is therefore of little value as a medicinal oil and it does not appear likely to be of any mining value.

EUCALYPTUS PYRIFORMIS.

E. pyriformis is a small shrub or mallee with long, weak and straggling stems up to 15 feet in height. It is widely distributed in Western and South Australia, occurring, in this State, between the Murchison and Moore Rivers, at least as far west as Coorow and south-east to Tammin; its eastern limit does not appear to have been defined.

The wood is pale brown in colour, and the bark light brown and smooth. The leaves are large and broadly lanceolate, being up to nearly 6 inches long and nearly 2 inches wide; the surface is subglaucous, the lamina freely dotted with oil glands and the venation that of the cineol-pinene type.

The material used in this investigation was collected by Mr. John Baxter towards the end of May, 1937. It was obtained from typical specimens in an area about 11 miles east of Marchagee, and was identified by Mr. G. R. W. Meadly, Assistant Government Botanist.

The oil, which distilled completely in from 4 to 5 hours, was pale yellow in colour and had a pleasant, non-irritating smell similar to that of the cineol-pinene oils. Its solubility in alcohol was low and it contained an appreciable amount of pinene, more than 14 per cent. of the oil distilling below 164°. The cineol content was 56 per cent. Esters were present in small amount and they were practically all low boiling; geranyl acetate was present in traces only. Both low- and high-boiling aldehydes were present, and the oil contained, in addition, aromadendrene and a small amount of a substance giving a purple colour with ferric chloride. The saponification values of the acetylated oil indicated that alcohols other than geraniol were present, and an appreciable amount of crystalline eudesmol was separated from the oil on redistillation. Fractionation of the oil showed that little more than 80 per cent. was volatile below 195° at ordinary pressure; the cineol content of this rectified oil was approximately 70 per cent. The separation of insoluble matter was again noted as boiling commenced.

EXPERIMENTAL.

EUCALYPTUS ASTRINGENS.

The dried oil had the following properties (physical properties given at 20°):—Specific gravity, 0.911; refractive index, 1.469; specific rotation, +7.3°; soluble in 1.1 volumes of 80 per cent. alcohol; acid value, 1.0; saponification values: hot 8.0, cold 5.0; saponification values of the acetylated oil: hot 38.7, cold 27.6, the latter corresponding to 6.2 per cent. of alcohols calculated as geraniol; cineol, 49.5 per cent.; aldehydes, 0.054 milligram mol per gram of oil.

On redistillation, the following fractions were obtained:—

Fraction.	Boiling Range.		Amount.	Specific Gravity.	Refractive Index.	Specific Rotation.
1.	Up to 165°	..	22.2 per cent.	0.894	1.464	+22.2°
2.	165—180°	..	49.7 per cent.	0.905	1.464	+ 9.6°
3.	180—195°	..	9.2 per cent.	0.928	1.468	— 7.1°

The residue (18.9 per cent.) was further distilled under reduced pressure.

4.	90—105°/26mm.	2.1 per cent.	0.948	1.482	—19.4°
5.	105—130°/25mm.	3.7 per cent.	0.953	1.495	—18.3°
6.	130—155°/24mm.	5.5 per cent.	0.945	1.500	— 2.3°
7.	155—168°/24mm.	4.7 per cent.	0.970	1.503	— 4.3°

From the residue, 0.65 per cent. of white solid was separated by adding ether and filtering.

Fraction 1 was yellow in colour, acidic, and contained volatile aldehydes. Pinene was present in quantity and was isolated as its nitrosochloride.

Fraction 2 was pale yellow in colour and contained a little over 60 per cent. of cineol. Its cold and hot saponification values were 7.6 and 11.6 respectively, whilst the corresponding values for the acetylated oil were 25 and 29. It contained a trace of aldehyde.

Fraction 3 was colourless and contained 71 per cent. of cineol; its hot saponification value was 5 and the corresponding figure for the acetylated oil was 87. It contained no aldehyde.

Fraction 4 was colourless, contained no aldehydes and gave no colouration with ferric chloride.

Aldehydes were present in the last three fractions, with maximum amount in fraction 6. Aromadendrene was present in greatest amount in fractions 5 and 6. With ferric chloride, a trace of olive green colour was obtained with fraction 6, and a purple colour with fraction 7.

EUCALYPTUS PYRIFORMIS.

The oil was obtained in from 1.0 to 1.1 per cent. yield, and, after drying, it had the following properties:—Specific gravity, 0.920; refractive index, 1.469; specific rotation, +8.4°; soluble in 1 volume of 80 per cent. alcohol; acid value, 0.65; ester value: cold, less than 0.1, hot, 3.35; saponification values of acetylated oil: cold 30.6, hot 56.7, the former corresponding to 8.3 per cent. of alcohols calculated as geraniol, and the difference corresponding to 8.8 per cent. of alcohols calculated as eudesmol; cineol, 56 per cent.; aldehydes, 0.04 milligram mol per gram of oil. The oil gave the usual colour reactions for aromadendrene and gave, slowly, a purple colouration with ferric chloride.

On redistillation, the following fractions were separated:—

Fraction.	Boiling Range.	Amount.	Specific Gravity.	Refractive Index.	Specific Rotation.
1.	Up to 164°	14.6 per cent.	0.890	1.463	+22.2°
2.	164—170° ..	30.2 per cent.	0.901	1.463	+11.4°
3.	170 -179° ..	31.2 per cent.	0.920	1.462	+ 2.5°

The residue (24 per cent.) was further fractionated under reduced pressure:-

4.	85 -100°/20mm.	5.6 per cent.	0.939	1.470	..
5.	100—125°/19mm.	3.9 per cent.	0.962	1.490	.
6.	125—150°/19mm.	3.2 per cent.	0.962	1.496	..
7.	150—165°/19mm.	7.2 per cent.	. ..	1.505	..

From the residue, 0.77 per cent. of insoluble material was separated by addition of ether and filtering.

Fraction 1 was practically colourless and contained a considerable quantity of *d*-pinene which was readily isolated as its nitrosochloride. It was strongly acidic and contained, in addition, cineol and a small amount of volatile aldehyde.

Fraction 2 was colourless and also contained an appreciable amount of *d*-pinene. With fraction 3, it contained practically the whole of the esters present in the oil. The cineol content was nearly 60 per cent. and aldehydes were present in traces.

Fraction 3 contained 80 per cent. of cineol, had a saponification value of 7.1, and contained a trace of aldehyde. Fraction 4 was similar, although the cineol content was lower.

Fractions 5, 6 and 7 all contained aromadendrene (maximum amounts in fractions 5 and 6) and high boiling aldehyde (maximum in fraction 6).

Fraction 7 was pale yellow in colour and gave a purple colour with ferric chloride. It solidified on standing, and from the solid material crystalline eudesmol (m.p. 79°) was separated in quantity.

The authors are indebted to Mr. W. G. Chandler and Mr. J. Baxter for the collection, and to Mr. C. A. Gardner and Mr. G. R. W. Meadly for the identification of material.

Reference:

1937: Langlands—Properties of Australian Timbers, Part 2—Brown Mallet (*E. astringens*). *Coun. Sci. Ind. Res.* (*Aust.*), Pamphlet 73.

Perth Technical College.

8.—UPPER EOCENE FORAMINIFERA FROM DEEP BORINGS IN KING'S PARK, PERTH, WESTERN AUSTRALIA.

By WALTER J. PARR, F.R.M.S.

Read 14th December, 1937: Published 12th July, 1938.

Communicated by PROFESSOR E. DEC. CLARKE.

INTRODUCTION.

During the course of boring operations for artesian water in King's Park, Perth, in 1930 and 1931, a number of samples of the rocks met with were obtained. These were examined by Mr. S. E. Terrill, of the Geology Department of the University of Western Australia, who recognised the presence of foraminifera. In July, 1931, Miss Lucy Hosking, B.A., now Mrs. N. J. Hanrahan, also of the Geology Department, forwarded a number of the samples to the writer with the request that they be examined with a view to seeing whether the foraminifera could be used for the purpose of zoning the coastal plain beds. Notes on the species identified were shortly afterwards supplied to Miss Hosking.

In October, 1933, Professor E. deC. Clarke sent a further set of samples from a second boring which had been put down in King's Park, with a note that they probably contained some foraminifera which might be suggestive of the age of the beds.

These samples were also examined, but the assemblage of foraminifera appeared to contain Cretaceous and Tertiary elements and the published work at the time did not then permit of a satisfactory determination of the age of the beds. In 1935, Chapman and Crespin (1935 a, p. 126), on information furnished by the writer, placed the lignitiferous shale occurring at 780 feet in the first bore in the Lower Oligocene and stated that the beds above the shale were possibly Upper Oligocene.

During the last two or three years, several papers have been published in America by Dr. J. A. Cushman, either alone or in collaboration with others, on Eocene faunas from the United States, which bear a striking resemblance to that found in the King's Park bores. These have enabled the age of the King's Park foraminifera to be determined as Upper Eocene. The evidence for this is given in the following paper.

The only previous record of Eocene marine beds from Australia is that of Chapman and Crespin (1935, pp. 55-62) from the North-West Division of Western Australia. The age of these, determined upon the larger foraminifera, of the genera *Discocyclina* and *Pellatispira*, was given as Middle to Upper Eocene. The finding of a faunule of smaller foraminifera of Eocene age in the vicinity of Perth is, therefore, of much interest, and the writer is deeply indebted to Professor Clarke and his staff for the opportunity of examining and describing it. Professor Clarke has also kindly furnished references to the published literature in relation to the rocks underlying Perth.

My best thanks are also due to the Commonwealth Palaeontologist, Miss Irene Crespin, B.A., for suggesting an Eocene age for the beds, and to my friend and collaborator, Mr. Frederick Chapman, the first Commonwealth Palaeontologist, for his assistance in many ways.

NOTES ON THE SAMPLES.

Little is published or known concerning the rocks underlying Perth. The fullest information is given by Forman (1933, pp. 44, 45) in his "Final Report on the Correlation of the Artesian Bores of the Metropolitan Area." Forman states:—

> "The base of the coastal limestone series, consisting of current bedded calcareous sandstones, lies at elevations varying from sea-level to as much as 180 feet below sea-level in different parts of the Metropolitan Area.
>
> "Underlying the coastal limestone series there are lacustrine deposits of calcareous shales and sandstones passing downwards into a series of marine beds of calcareous shales or mudstones, sandstones and impure limestones. All of the beds are extremely lenticular.
>
> "Under the Metropolitan Area there are three distinct artesian water-bearing horizons. These horizons can be distinguished by water analyses, static heads and temperatures of the various flows. The horizons when contoured from bore to bore are found to be unconformable and it is suggested that the water-bearing horizons lie on the surface of the unconformities, because of the frequent occurrence of extremely coarse sands and small boulders in the water bearing zones. These sands are in distinct contrast to the fine-grained nature of the sediments throughout the series.
>
> "Of the three horizons, the upper two have a limited distribution. The upper horizon is met with in the bores in the vicinity of the city and at Osborne Park, and it is thought that the bores in the Guildford District also draw their water from this horizon. The second horizon is met with in the bores in the Leederville District and in the King's Park bores on Mount's Bay Road. The third horizon covers a larger area, having been encountered in all bores of sufficient depth."

The samples* examined by the writer are from depths between 120 feet and 780 feet in King's Park Bore No. 1, and between 230 feet and 1,950

*In connection with the depths assigned to these samples it should be noted that a percussion plant was used, casing being kept within a few feet of the bottom. Although some mixing of material must take place under these conditions, experienced drillers say that the range of contamination is not more than 50 feet. Samples of the "country" were taken at every noticeable change in the rocks, or, if the rocks did not change, at every 20 feet, and consisted of the contents of the first haul of the sand pump from that depth. Actually, however, the samples sent for palaeontological examination were all obtained by scraping the bit when it was raised preliminary to sand-pumping. The drillers consider that these are undoubtedly true samples for the depths quoted.

It may be added that, as the beds from which the foraminifera were obtained are clearly all of the same age and, with the exception of the sample from 780 ft. in Bore No. 1, show similar conditions of sedimentation, the effect of possible contamination of samples is here relatively unimportant. It has, however, been looked for, as differences in the mode of preservation of the foraminifera in the various samples have usually facilitated the detection of any admixture of specimens from a higher level.

feet in King's Park Bore No. 2. The foraminifera occur in all of the samples from the first bore, but in the second bore are confined to those above 780 feet, at which depth a dark grey unfossiliferous shale occurs. This, Professor Clarke informs me, is the cover bed of the upper artesian water horizon (i.e., Forman's second horizon, W.J.P.). Between 780 and 1950 feet, the samples are unfossiliferous and apparently represent deposits of fresh water origin. Particulars of these are as follows:—

1030 feet: Sandstone with shale bands. Professor Clarke states that the bailer also brought up granite pebbles and boulders, apparently underlying this bed.

1210 feet: Brownish-grey loosely consolidated sand. The sand grains measure up to 4mm. in diameter and are sub-angular to rounded in outline.

1558 feet: Dark-grey pyritous sandy clay, the sand grains being generally sub-angular.

1772 feet: Clay of similar character to that from 1558 feet. This immediately overlies the second water horizon.

1950 feet: Fine-grained compact grey shale.

While fossiliferous beds do not occur in the King's Park bores below 780 feet, Miss Crespin has informed me that, in samples she has recently examined from the Perth area, she has also met with Lower Cretaceous foraminifera. These occur in the Zoological Gardens Bore below 1680 feet down to 1750 feet, and in the Leederville Valley Bore at 1650 feet down to 1746 feet. Above these, strata with foraminifera similar to those in the King's Park Bores are present.

With the exception of the sample from 780 feet in Bore No. 1, which is a lignitiferous shale with *Cyclammina* as the only fossil, all of the fossiliferous material is of the same character. It is a light fawn-grey calcareous soft shale, which is intercalated between sandstone beds in the bores. After washing, the residues consist of foraminifera, nearly all of which are very small, broken sponge spicules, ostracods, a few bryozoa and radiolaria, and occasional poorly-preserved molluscs. There is also a large percentage of sand grains, mostly sub-angular, and some glauconite.

Mr. Leo. W. Stach, B.Sc., has kindly examined the bryozoa and his identifications are as follows:—

Crisia acropora Busk
Mesostomaria angustiloba (Busk)
Costaticella benecostata (Levinsen)
Idmonea sp.
Entalophora sp.

Mr. Stach states the three species identified have a known range from Janjukian (? Upper Oligocene) to the present time.

Of the sponges, the best-represented is the genus *Geodia*, the white reniform spicules of which are conspicuous in every sample. There are several examples of annulated spicules from 430 feet in Bore No. 2. These have been identified by Mr. F. Chapman as *Geodites* sp., a genus confined to Cretaceous and Eocene beds.

Sixty-nine species of foraminifera are here recorded from the bores. This does not represent all of the species present as a number, which are rare or represented by poorly preserved specimens, have been omitted.

The types have been deposited in the collection of the Geology Department of the University of Western Australia.

TABLE SHOWING DISTRIBUTION OF FORAMINIFERA IN THE BORES

Species— c—common. f—frequent. r—rare.	Depth of Sample. Bore No. 1. 120 ft.	492 ft.	530 ft.	563-573 ft.	610-620 ft.	640-660 ft.	710 ft.	755 ft.	770 ft.	780 ft.	Bore No. 2. 230 ft.	385 ft.	430 ft.	555 ft.	606 ft.	728 ft.	Geological Range.
1. *Lenticulina* sp.	r	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
2. *L. (Robulus) warmani* ...	r	...	...	...	...	f	...	...	...	...	r	...	r	...	r	...	L. Mio. U.S.A.
3. *L. (R.) gibba*	f	...	...	...	...	...	...	...	f	...	...	...	...	...	...	...	Terty.-Recent
4. *Marginulina* sp.	r	...	...	r	...	...	...	r	...	...	r	...	...	...	...	r	
5. *M. gladius*	f	...	...	...	...	...	...	...	...	...	...	...	...	r	...	...	Eocene-Olig.
6. *M. subbullata*	r	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	do.
7. *M.* sp.	...	...	...	...	...	r	...	...	...	...	...	f	c	...	...	...	
8. *Vaginulina subplumoides* ...	...	...	...	...	...	...	...	...	...	...	...	r	r	...	...	...	
9. *V.* sp.	...	...	...	...	...	...	...	...	...	...	...	r	...	...	...	...	
10. *Dentalina colei*	r	...	...	...	...	...	...	f	f	...	...	...	...	...	...	r	Eocene U.S.A.
11. *D. consobrina*	r	r	...	...	...	...	f	c	r	...	f	f	...	...	r	...	Terty.-Recent
12. *D. soluta*	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	...	do.
13. *D. fissicostata*	r	...	...	...	r	...	...	r	...	...	...	...	...	...	...	...	
14. *D. spinulosa*	...	...	...	...	...	...	r	r	r	...	...	...	...	...	...	r	Eocene-Olig.
15. *Nod.* aff. *raphanistrum* ...	r	...	...	...	...	...	...	r	...	...	r	...	...	...	r	...	
16. *N. longiscata*	r	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	Eocene-Pliocene
17. *N. radicula*	c	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Eocene-Recent
18. *Pseudoglandulina clarkei* ...	r	...	r	...	...	...	...	...	r	...	...	...	...	r	r	...	
19. *Frondicularia mucronata* ...	...	...	...	...	...	...	...	...	...	...	...	...	r	...	...	...	Up. Cret.-?Eocene
20. ? *Frondicularia* sp.	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	...	
21. *Lagena marginata*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	...	Terty.-Recent
22. *L. luciae*	...	...	...	...	...	...	...	r	...	...	...	...	...	r	...	r	
23. *L. acuticosta*	r	...	...	...	...	f	...	f	r	...	...	...	r	...	r	r	Cret.-Recent
24. *L. sulcata*	...	r	...	...	...	...	...	r	...	...	...	...	...	...	...	r	Terty.-Recent
25. *L. perthensis*	...	...	...	...	...	...	...	...	...	...	...	...	r	...	...	...	
26. *L. hexagona*	r	...	...	...	...	...	...	f	r	...	...	r	r	...	r	f	do.
27. *L. terrilli*	...	...	...	...	...	r	f	f	f	...	r	...	r	r	f	r	
28. *L. orbignyana*	...	...	r	...	...	...	...	r	...	...	...	r	...	...	...	...	do.
29. *Guttulina irregularis*	f	...	...	r	...	...	...	f	...	..	r	...	r	...	r	...	Eocene-Recent
30. *Globulina gibba*	...	...	...	f	...	f	r	f	r	...	...	f	...	...	c	r	do.
31. *G. rotundata*	r	...	...	...	...	...	...	...	...	...	...	...	...	...	r	...	do.

32. *Buliminella westraliensis* ...	...	...	f	r	r	...	f	f	r	...	...	...	...	r	r	c	
33. *Robertina* sp.	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	...	
34. *Angulogerina subangularis* ...	r	r	r	r	r	...	c	...	r	...	f	...	r	...	r	c	
35. *Cassidulina* sp.	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	...	
36. *Bolivinopsis crespinae* ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	f	
37. *B. eocenica*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	Eocene U.S.A.
38. *Gümbelina venezuelana*, var. *rugosa*	...	..	...	r	...	...	...	...	r	...	...	...	...	...	...	r	
39. *Patellina* sp. aff. *corrugata* ...	...	...	...	...	...	...	...	r	...	...	...	...	...	...	...	...	
40. *Discorbis assulatus*	...	...	r	...	...	...	...	...	...	...	...	...	...	r	r	f	Up. Eocene U.S.A.
41. *Heronallenia pusilla*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	
42. *Valvulineria sculpturata* ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	L. Olig. U.S.A.
43. *Ceratobulimina westraliensis* ...	c	...	r	...	...	...	f	c	...	...	c	r	f	f	f	c	
44. *Gyroidina soldanii*	c	...	...	r	...	r	...	f	r	...	r	r	r	...	r	f	
45. *G. soldanii*, var. *octocamerata*	...	...	r	...	...	...	...	f	...	...	r	r	...	...	...	...	Eocene U.S.A.
46. *Pulvinulinella obtusa*, var. *westraliensis*	r	r	...	r	...	...	...	c	r	...	f	r	c	r	c	c	
47. *Epistomina elegans*	f	...	...	...	...	...	...	...	...	...	r	...	f	...	...	r	Eocene-Recent
48. *Siphonina* sp.	...	r	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
49. *Anomalina perthensis* ...	...	...	...	r	...	...	...	...	...	...	...	f	r	...	f	f	
50. *A. westraliensis*	...	...	...	r	...	...	...	...	f	...	...	...	...	...	...	c	
51. *Cibicides lobatulus*	...	...	...	...	...	...	...	...	...	...	...	...	c	...	...	...	do.
52. *C. pseudoconvexus*	...	...	f	c	...	...	...	c	c	...	...	f	c	f	f	c	
53. *C. pseudoungerianus*	...	...	...	...	...	...	...	...	...	...	r	...	...	...	r	...	do.
54. *C. umbonifer*	f	f	...	c	...	f	r	...	...	...	f	r	r	r	f	c	
55. *Pullenia quinqueloba* ...	r	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	do.
56. *Globigerina triloba*	...	...	...	...	...	...	...	r	...	...	...	...	r	...	...	r	Olig. Recent
57. *G. inflata*	...	...	...	...	...	...	r	...	...	...	r	...	...	...	...	r	Eocene-Recent
58. *G. orbiformis*	r	...	...	...	...	r	...	f	f	...	r	f	f	...	f	f	U. Eocene Mexico
59. *Globorotalia chapmani* ...	r	...	...	...	...	...	...	...	r	...	...	r	...	...	...	c	
60. *Nonion novozealandicus* ...	c	r	...	...	...	...	r	r	c	...	c	f	c	...	c	c	L. Olig. N.Z.
61. *Ammodiscus* aff. *incertus* ...	r	...	...	...	...	...	...	...	...	...	r	...	...	...	...	...	
62. *Bathysiphon* sp.	...	r	f	r	...	r	...	...	...	...	...	...	c	f	c	c	
63. *Cornuspira involvens* ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	r	...	Eocene-Recent
64. *Quinqueloculina seminulum* ...	r	...	...	...	...	f	...	f	...	...	r	r	...	...	c	c	do.
65. *Q. vulgaris*	r	...	...	r	...	...	r	f	...	...	...	...	...	...	r	...	Terty.-Recent
66. *Q. venusta*	...	...	...	f	...	...	r	r	...	...	r	...	r	...	...	...	do.
67. *Cyclammina incisa*	r	...	r	...	...	c	r	r	r	r	...	r	c	c	c	c	Eocene-Miocene
68. *Spiroplectammina* sp. ...	...	...	...	r	...	...	...	r	...	...	...	...	...	...	...	r	
69. ? *Gaudryina subquadrata* ...	...	...	...	...	...	...	...	f	...	...	...	...	...	...	...	...	

SUPERFAMILY **SPIRILLINOIDEA.**

FAMILY **NODOSARIIDAE.**

Genus **LENTICULINA** Lamarck, 1804.

Lenticulina sp.

Plate I, figs. 1 *a, b.*

The unique specimen figured represents a form near *L.* (*Robulus*) *simplex* (d'Orbigny), described from the Miocene of the Vienna Basin, but has more chambers and the robuline slit is absent.

Subgenus ROBULUS Montfort, 1808.

Lenticulina (Robulus) warmani (Barbat and von Estorff).

Plate I, figs. 2 *a, b.*

Robulus nikobarensis (Schwager), var. *warmani* Barbat and von Estorff, 1933, p. 168, pl. xxiii, figs. 12 *a, b.*

R. warmani B. & v. E. : Cushman and Hobson, 1935, p. 56, pl. viii, figs. 8 *a, b.*

This species, described from the Lower Miocene of California, is represented by a number of typical examples

Lenticulina (Robulus) gibba (d'Orbigny).

Cristellaria gibba d'Orbigny, 1826, p. 292, No. 17; 1839, p. 63, pl. vii, figs, 20, 21; Cushman, 1923, p. 105, pl. xxv, fig. 4.

This species was originally described as a Recent form from the West Indies and there are numerous records as a fossil from Cretaceous and Tertiary deposits. The King's Park examples agree with specimens I have from off the Island of St. Thomas, in the West Indies.

Genus **MARGINULINA** d'Orbigny, 1826.

Marginulina sp.

Plate I, fig. 3.

The figure represents a species which I have been unable to identify. The apertural end of the test is missing but immature examples show that the aperture is radiate and slightly projecting at the peripheral angle and that the apertural face is broadly rounded.

Chapman (1917 p. 29, pl. viii, figs. 73, 74) has figured, under the names of *Cristellaria gladius* and *C. acutauricularis,* what appears to be the present species, fig. 73 representing the adult form and fig. 74 an immature specimen. His records were from the Upper Cretaceous of Gingin, W.A.

Marginulina gladius (Philippi).

Plate I, fig. 5.

Marginulina gladius Philippi, 1843, p. 40, pl. i, fig. 37.

Cristellaria gladius (Phil.) : Hantken, 1876, p. 51, pl. v, fig. 12. Nuttall, 1928, p. 89, pl. v, figs. 11, 18.

I have been unable to see Philippi's work in which this species was described. Except that they are shorter, the King's Park specimens agree in essentials with Hantken's figure of this species from the Lower Oligocene of Hungary. A comparison made of a large series of specimens from beds at Kiscell, Hungary, of the same age as those studied by Hantken, shows

the amount of sutural limbation to vary greatly, as in the King's Park examples, the sutures being smooth in some specimens, while, in the best developed examples they are heavily limbate and raised.

The elongate compressed *Marginulinae,* with limbate or beaded sutures, are common in the Eocene and Oligocene.

Marginulina subbullata Hantken.

Plate I, fig. 6.

Marginulina subbullata Hantken, 1876, p. 39, pl. iv, figs. 9, 10; pl. v, fig. 9. Nuttall, 1935, p. 125, pl. xiv, fig. 16.

The figured specimen agrees fairly well with the shorter, apparently megalospheric, examples I have of Hantken's species from the Lower Oligocene of Hungary. There is a very typical specimen in the Commonwealth Palaeontological Collection at Canberra from Claremont Bore No 1, 750-850 feet. This form appears to grade into *M. bullata* Reuss, a Cretaceous species, and *M. pachygaster* Gümbel, from the Eocene.

Marginulina sp.

There are numerous broken examples of a species of *Marginulina* resembling *M. costata* (Batsch) in form, but with about twenty-four costae instead of the usual twelve to fourteen found in Batsch's species.

Genus **VAGINULINA** d'Orbigny, 1826.

Vaginulina subplumoides, sp. nov.

Plate I, fig. 7.

Test much compressed, faces parallel, initial end pointed and with a small spine, dorsal margin almost straight, ventral margin at first curved outwards, then curved backwards towards the apertural end; chambers numerous, long and narrow; sutures distinct, but largely obscured by the ornament of longitudinal costae, which are not continuous throughout the length of the shell; aperture at the dorsal angle, radiate. Length up to 1mm.; width, up to 0.4 mm.

Holotype from King's Park Bore No. 2, 385 feet.

Five examples were found. This is an interesting species belonging to the group of *Vaginulinae* with intermittent, longitudinal costae. The group is generally characteristic of Mesozoic deposits, the only Tertiary species with which I am acquainted being *V. plumoides* Plummer, from the Eocene (Midway) of Texas, U.S.A. The present species differs from *V. plumoides,* an example of which I have through the kindness of Mrs. Plummer, in its broader outline and differently shaped early portion. *V. intumescens* Reuss, a Lower Cretaceous species, is also somewhat similar, but has fewer and wider chambers.

Vaginulina sp.

Plate I, fig. 4.

The figure represents a unique example, 0.45 mm. in length, of a species of *Vaginulina.* It bears some resemblance to the Recent species, *V. patens* Brady, which occurs on the east coast of Australia and off the Philippines, but has a narrower test, without the initial spine of Brady's species.

Genus **DENTALINA** d'Orbigny, 1826.

Dentalina colei Cushman and Dusenbury.

Plate I, fig. 8.

Vaginulina legumen (Linné), var. *elegans* Cole (non *V. elegans* d'Orbigny), 1927, p. 21, pl. iii, figs. 10-11.

Dentalina colei Cushman and Dusenbury, 1934, p. 54, pl. vii, figs. 10-12.

Examples are fairly common and typical. In describing this species, Cushman and Dusenbury point out that the true *V. elegans* has a compressed test, with strongly elevated sutures, and was described from Recent material. The Eocene form to which this name has been assigned has its sutures flush with the surface and is compressed only in the first few chambers. The types of *Dentalina colei* were from the Upper Eocene (Poway conglomerate) of California. Cole's specimens were from the Middle Eocene (Guayabal) of Mexico.

Dentalina consobrina d'Orbigny.

Dentalina consobrina d'Orbigny, 1846, p. 46, pl. ii, figs. 1-3.

Nodosaria (*Dentalina*) *consobrina* (d'Orb.): Chapman and Parr, 1926, p. 381, pl. xviii, fig. 33.

The typical form of this species is represented by a number of broken examples. With these are others with much longer chambers. The latter are similar to the specimens referred to *D. consobrina* and figured by Cushman and G. D. Hanna (1927, p. 214, pl. xiii, figs. 12, 13) from the Eocene of California.

Dentalina soluta Reuss.

Dentalina soluta Reuss, 1851, p. 60, pl. iii, figs. 4 *a, b*.

Nodosaria (*Dentalina*) *soluta* (Rss.): Chapman and Parr, 1926, p. 383, pl. xix, fig. 40.

One two-chambered specimen and a three-chambered fragment are referred to this species, which was described from the Oligocene of Germany. Cushman (1935, p. 21, pl. viii, figs. 15, 16) has figured similar specimens as *Dentalina* sp. ? from the Upper Eocene of U.S.A.

Dentalina fissicostata Gumbel.

Dentalina fissicostata Gumbel, 1870, p. 626, pl. i fig. 46.

Nodosaria fissicostata (Gumbel): Cushman, 1935, p. 22, pl. v, figs. 8, 9.

Recognizable fragments of this species occur. The types were from the Eocene of Germany and records subsequently include the Upper Eocene of South-eastern United States (Cushman) and the Miocene of Victoria (Chapman and Parr).

Dentalina spinulosa (Montagu).

Plate I, fig. 9.

Nautilus spinulosa Montagu, 1808, p. 86, pl. xix, fig. 5.

Dentalina spinulosa (Mont.): Sherborn and Chapman, 1886, p. 751, pl. xv, fig. 13.

Nodosaria spinulosa (Mont.): Plummer, 1926, p. 84, pl. iv, figs. 19 *a-c*.

There are several fragments bearing the characteristic ornament. This species is common in the Eocene (London Clay) of Piccadilly, England, and in the Eocene (Midway) of Texas, U.S.A. Mrs. Plummer (loc. cit.) notes its occurrence in the Upper Cretaceous of Texas.

Genus **NODOSARIA** Lamarck, 1812.

Nodosaria sp. aff. **raphanistrum** (Linné).

Single chambers, apparently of this species, occur fairly frequently. They measure up to 1 mm. in length, with a similar diameter, and are ornamented with twelve heavy costae, the outside edge of which is flat.

Nodosaria longiscata d'Orbigny.

Nodosaria longiscata d'Orbigny, 1846, p. 32, pl. i, figs. 10-12. Chapman and Parr, 1926, p. 379, pl. xviii, fig. 23.

Fragments are fairly common. The examples represent a more robust form of this species than is usually met with and the chambers are proportionately shorter. Topotype examples from the Miocene of the Vienna Basin show, however, that this form occurs with the slenderer specimens at the type locality. The range of *N. longiscata* is from Eocene to Pliocene.

Nodosaria radicula (Linné).

Plate I, fig. 10.

Nautilus radicula Linné, 1767, p. 1164; 1788, p. 3373, No. 18.

Nodosaria radicula (Lin): Plummer, 1926, p. 77, pl. iv, figs. 9 *a, b*.

Typical examples occur. The figured specimen differs from the others in having the penultimate chamber smaller than the adjoining chambers.

Genus **PSEUDOGLANDULINA** Cushman, 1929.

Pseudoglandulina clarkei, sp. nov.

Plate I, fig. 11.

Test ovate, longer than broad, the apertural half the wider, circular in transverse section; chambers few, overlapping, indistinct; initial end bluntly rounded; aperture radiate and projecting; wall smooth.

Length up to 1 mm.; diameter to 0.7 mm.

Holotype from King's Park Bore No. 2, 606 feet.

This species is somewhat similar to many of the figures given of *Glandulina laevigata* (d'Orb.) by authors. In the microspheric form of *G. laevigata*, the early chambers are arranged as in *Pyrulina*. One microspheric example of the present species was found and this shows that the initial chambers are as in *Marginulina*. The species is accordingly referred to *Pseudoglandulina*.

The species is named in honour of Professor E. de C. Clarke.

Genus **FRONDICULARIA** Defrance, 1824.

Frondicularia mucronata Reuss.

Plate I, fig. 12.

Frondicularia mucronata Reuss, 1845, p. 31, pl. xiii, figs. 43, 44; 1874, p. 96, pl. xxi, figs. 14-16.

There is one example which agrees with figures 15 and 16 of Reuss's 1874 paper. The species was described from the Upper Cretaceous of Bohemia. Mrs. H. J. Plummer (1926, p. 115, pl. v., fig. 3) has recorded a very similar species under the name of the later-described *F. goldfussi* Reuss from the Lower Eocene (Midway) of Texas, U.S.A.

(?) **Frondicularia** sp.

There is one broken example of a frondicularian form with the characteristic ornament of the Upper Cretaceous species, *Flabellina reticulata* Reuss. The early portion of the test is broken off, but, as the shell does not flare as in *F. reticulata,* it is probable that the species is not that described by Reuss.

Genus **LAGENA** Walker and Jacob, 1798.

Lagena marginata (Walker and Boys).

Serpula (*Lagena*) *marginata* Walker and Boys, 1784, p. 2, pl. i, fig. 7.

There is one specimen with a moderately-compressed pyriform test and a subacute, narrow, marginal keel. This is the typical form of the species.

Lagena luciae, sp. nov.

Plate I, fig. 13.

Test globose, a little longer than broad; base bluntly pointed, apertural end produced and ornamented with a few weak spiral costae, body of test ornamented with five evenly-spaced carinae, each of which is regularly tubulated, with the tubules directed towards the base of the shell; wall translucent. Length up to 0.19 mm.

Holotype from King's Park Bore No. 2, 555 feet.

This minute species occurs in several of the samples. It is named in honour of Mrs. N. J. Hanrahan, formerly Lucy F. V. Hosking.

Lagena acuticosta Reuss.

Lagena acuticosta Reuss, 1862, p. 305, pl. i, fig. 4; Cushman and Ponton, 1932, p. 59, pl. vii, figs. 20 *a*, *b*.

Records of this species are from Cretaceous to Recent. Many of the King's Park examples are proportionately a little longer than in the form as figured by Reuss, but are otherwise typical.

Lagena sulcata (Walker and Jacob).

Serpula (*Lagena*) *sulcata* Walker and Jacob, 1798, p. 634, pl. xiv, fig. 5.
Lagena sulcata (W. & J.): Brady, 1884, p. 462, pl. lvii, figs. 23, 26, 33, 34.

Small specimens occur, with weaker costae than usual.

Lagena perthensis, sp. nov.

Plate I, fig. 14.

Test somewhat pyriform, about one and a half times as long as broad, circular in cross section, base bluntly pointed, apertural end produced, with a short neck; wall of the test covered with very numerous fine longitudinal costae which are connected by delicate cross bars; the apertural end ornamented with small, shallow rounded pits. Length up to 0.43 mm.

Holotype from King's Park Bore No. 2, 430 feet.

I do not know of any described species with which this could be compared. It has a distinctive glistening appearance, due to the play of light on the very delicate reticulate ornament.

Lagena hexagona (Williamson).

Entosolenia squamosa (Montagu), var. *hexagona* Williamson, 1848, p. 20, pl. ii, fig. 23; 1858, p. 13, pl. i, fig. 32.
Lagena hexagona (Will.): Cushman, 1923, p. 24, pl. iv, fig. 6.

Typical examples occur.

Lagena terrilli, sp. nov.

Plate I, fig. 15 *a, b*.

Test small, nearly circular in outline, compressed, slightly inflated in the central portion of each face, peripheral margin with two strong encircling keels which are separated by a shallow groove; the chamber faces ornamented with minute pits in more or less concentric rows; aperture an oval fissure at the end of a short broad neck. Length up to 0.36 mm.

Holotype from King's Park Bore No. 2, 430 feet.

This species is fairly common in the samples. It resembles the Recent species, *L. clathrata* Brady, in outline and apertural characters, but differs from that species in being bicarinate and with the surface pitted instead of costate.

The name is given in honour of Mr. S. E. Terrill.

Lagena orbignyana (Seguenza).

Fissurina orbignyana Seguenza, 1862, p. 66, pl. ii, figs. 24, 26.
Lagena orbignyana (Seg.): Brady, 1884, p. 484, pl. lix, figs. 1, 18, 24-26. Cushman, 1923, p. 40.

The specimens are similar to Brady's fig. 25, but are more inflated, so are similar to the form of *L. orbignyana* which is common in the Lower Miocene of Victoria.

FAMILY **POLYMORPHINIDAE.**

Genus **GUTTULINA** d'Orbigny, 1826.

Guttulina irregularis (d'Orbigny).

Plate II, figs. 1 *a, b*.

Globulina irregularis d'Orbigny, 1846, p. 226, pl. xiii, figs. 9, 10.
Guttulina irregularis (d'Orb.): Cushman and Ozawa, 1930, p. 25, pl. iii, figs. 4, 5; pl. vii, figs. 1, 2.

Typical examples, measuring up to 1.2 mm. in length occur. Cushman and Ozawa's earliest record of this species is from the Eocene.

Genus **GLOBULINA** d'Orbigny, 1826.

Globulina gibba d'Orbigny.

Globulina gibba d'Orbigny, 1826, p. 266, No. 10; Modèles No. 63. Cushman and Ozawa, 1930, p. 60, pl. xvi, figs, 1-4.

Small examples are common. The geological range of this species is from Eocene to Recent.

Globulina rotundata (Bornemann).

Plate II, figs. 2 *a, b.*

Guttulina rotundata Bornemann, 1855, p. 346, pl. xviii, fig. 3.
Globulina rotundata (Born.): Cushman and Ozawa, 1930, p. 86, pl. xxi, figs. 3, 4. Cushman, 1935, p. 27, pl. ix, fig. 24 *a c.*

This species was described from the Oligocene of Germany and its geological range extends from Eocene to Recent.

FAMILY BULIMINIDAE.

Genus BULIMINELLA Cushman, 1911.

Buliminella westraliensis, sp. nov.

Plate II, figs. 3, 4.

Test elongate, subcylindrical, more or less twisted in contour, initial end blunt, apertural end rounded; chambers numerous, long and narrow, added obliquely and arranged in a spiral series of about two and a half coils in the adult; sutures distinct, wall smooth; aperture elongate and narrow, in a semi-circular depression just below the end of the test. Length up to 0.40 mm; diameter to 0.1 mm.

Holotype from King's Park Bore No. 1, 755 feet.

This is one of the most distinctive species in the samples. It is subject to a good deal of variation, some of the shorter, apparently juvenile specimens being close to *B. elegantissima* (d'Orb). Generally, however, the examples are like the holotype, when the form of the test and the arrangement of the chambers are intermediate between d'Orbigny's species and *Buliminoides williamsonianus* (Brady).

Genus ROBERTINA d'Orbigny, 1846.

Robertina sp.

Plate II, fig. 5.

This genus is represented by a single example of a form near *R. californica,* a species recently described by Cushman and Parker (1936, p. 97, pl. xvi, figs. 14 *a, b.*) from the Pliocene of California. The specimen is apparently a little flattened and the apertural side is obscured by adherent sand grains, hence a closer determination is not possible. The occurrence of this genus in the King's Park bores is of interest as it is not known to occur earlier than the Eocene. While it has not been previously recorded from Australia, it occurs in the Lower Miocene of Victoria.

Genus ANGULOGERINA Cushman, 1927.

Angulogerina subangularis, sp. nov.

Plate II, figs, 6 *a, b.*

Test elongate, about four times as long as broad, sub-triangular in transverse section, with blunt angles, early portion of the test rapidly enlarging and often almost circular in section, the triangular character more pronounced in the later portion of the test, the sides of which are almost parallel; chambers numerous, distinct, slightly inflated, at first regularly

triserial, then loosely triserial and gradually increasing in height; sutures distinct, slightly depressed; wall smooth, finely perforate; aperture circular, terminal, at the end of a short neck. Length up to 0.35 mm.; diameter to 0.09 mm.

Holotype from King's Park Bore No. 1, 770 feet.

This is a common form in the bore samples. It resembles *A vicksburgensis*, described by Cushman (1935a, p. 33, pl. v, figs. 3, 4) from the Lower Oligocene (Byram Marl) of U.S.A. *A. subangularis* is proportionately longer, with more chambers, a longer, regularly-triserial series, and it does not terminate in the distinct neck with phialine lip of Cushman's species.

Uvigerina canariensis d'Orb., var *australis* Heron-Allen and Earland, from the Lower Miocene of Batesford, Victoria, is another species belonging to the same group.

FAMILY **CASSIDULINIDAE.**

Genus **CASSIDULINA** d'Orbigny, 1826.

Cassidulina sp.

Plate II, fig. 7.

This genus is represented by a single specimen of a form somewhat similar to *C. subglobosa* Brady, but with more numerous chambers.

FAMILY **HETEROHELICIDAE.**

Genus **BOLIVINOPSIS** Yakovlev, 1891.

Bolivinopsis crespinae, sp. nov.

Plate III, figs. 11 *a, b*.

Test minute, much compressed, about twice as long as wide, initial end rounded, apertural end bluntly pointed, early portion planispirally coiled and forming the widest and thickest part of the test, later portion biserial and with the sides almost parallel; adult chambers numbering four to six, about as high as wide; sutures very distinct, in the biserial portion sharply reflexed, not depressed; wall smooth and polished, calcareous, finely perforate. Length up to 0.2 mm.; width to 0.1 mm.

Holotype from King's Park Bore No. 2, 728 feet.

This is one of the smallest foraminifera occurring in the samples. It is fairly common in Bore No. 2, at 728 feet. No previously-described species closely resembles it. It is named in honour of Miss Irene Crespin, B.A., the Commonwealth Palaeontologist.

The genus *Bolivinopsis*, or as it is better known, *Spiroplectoides*, is most usually found in the Upper Cretaceous, but there are two Eocene species known and a Recent record of *B. rosula* (Ehrenberg) by Heron-Allen and Earland from the vicinity of the Falkland Islands.

Bolivinopsis eocenica (Cushman and Barksdale).

Spiroplectoides eocenica Cushman and Barksdale, 1930, p. 66, pl. xii, figs. 5 *a, b*. Cushman, 1934, p. 43, pl. vi, figs. 28 *a, b*.

There are two specimens from Bore No. 2, 728 feet, which seem to be identical with this species, the types of which were from the Eocene of California. This has very low chambers in the biserial portion and the sutures, while distinct, are not thickened and reflexed like those in *B. crespinae*, which occurs in the same sample.

Genus **GÜMBELINA** Egger, 1899.

Gümbelina venezuelana Nuttall, var. **rugosa**, var. nov.

Plate II, figs. 8 *a, b*.

Nuttall (1935, p. 126, pl. xv, figs. 2-4) described *G. venezuelana* as follows:—Test small, compressed, somewhat flattened, short; tapered to an acute initial end. Border rounded, lobate. Chambers inflated, smooth, separated by narrow depressed sutures. Aperture an oval, arched opening, extending from the base of the last chamber for about one-third of the distance towards the periphery. The width of the aperture is less than the length. Average length 0.4 mm., width 0.4 mm. The types were from the Upper Eocene of Venezuela.

The King's Park specimens agree in form, arrangement of chambers and apertural characters with Nuttall's specimens, but the earlier chambers have a papillate surface. The only other *Gumbelina* with such a surface appears to be *G. wilcoxensis*, described by Cushman and Ponton (1932, p. 66, pl. viii, figs. 16, 17) from the Upper Eocene of Alabama. This is a short broad form with a low aperture.

Length of variety, 0.25 mm.; width, 0.2 mm.

Holotype of variety from King's Park Bore No. 1, 770 feet.

FAMILY **ROTALIIDAE**.

Genus **PATELLINA** Williamson, 1858.

Patellina sp. aff. **corrugata** Williamson.

There is one small example measuring 0.21 mm. in diameter. The chambers are more finely subdivided than in *P. corrugata*, but not so finely as in *P. advena* Cushman. The specimen appears to most nearly resemble *P. corrugata*.

Genus **DISCORBIS** Lamarck, 1804.

Discorbis assulatus Cushman.

Plate II, figs. 9 *a-c*.

Discorbis assulata Cushman, 1933, p. 15, pl. ii, figs. 2 *a-c*. 1935, p. 44, pl. xvii, figs. 1, 2.

This species was described from the Upper Eocene (Ocala limestone) of Georgia, U.S.A. The King's Park specimens are typical, except that they show no tendency to a lobulate periphery.

Genus **HERONALLENIA** Chapman and Parr, 1931.

Heronallenia pusilla, sp. nov.

Plate II, figs. 11 *a-c*.

Test very small and almost flat, nearly circular in outline, consisting of four crescentic chambers; chamber wall smooth; sutures comparatively broad, evenly recurved on the dorsal side, on the ventral side strongly reflexed; aperture an elongate, arched slit extending from the spiral suture half-way across the ventral face of the last-formed chamber towards the periphery; wall around the aperture radially ribbed. Maximum diameter, 0.23 mm.

Holotype from King's Park Bore No. 2, 728 feet.

This species is represented by a single example, but the form is so distinct as to justify its being described as new. The genus does not appear to have been previously recorded from beds older than the Oligocene.

Genus **VALVULINERIA** Cushman, 1926.

Valvulineria sculpturata Cushman.

Plate II, figs. 10 *a-c*.

Valvulineria sculpturata Cushman, 1935 a, p. 37, pl. v, figs. 10 *a-c*.

This is one of the most interesting species met with. It was described by Cushman from the Lower Oligocene of Mississippi, U.S.A., and is here represented by one typical example.

Genus **CERATOBULIMINA** Toula, 1920.

Ceratobulimina westraliensis, sp. nov.

Plate II, figs. 12 *a-c*.

Test slightly longer than broad, compressed, umbilicate on the ventral side; periphery rounded; chambers numbering seven to eight in the last-formed whorl; sutures thickened and sometimes limbate and raised in the early portion of the test, depressed in the later portion of the shell; wall thick and polished; aperture a slit at the base of the inner margin of the last-formed chamber, septal face of chamber with a median umbilical notch and dent of varying width. Length up to 0.5 mm.; width to 0.4 mm.; thickness to 0.25 mm.

Holotype from King's Park Bore No. 2, 230 feet.

This is one of the common species in the samples. *C. perplexa* (Plummer), from the Eocene (Midway) of Texas, U.S.A., is fairly closely related, but has only six chambers to the adult whorl and a smaller and more rounded umbilical depression than the present species. *C. westraliensis* also has generally a much larger umbilical notch than *C. perplexa,* although it is variable in this respect.

Genus **GYROIDINA** d'Orbigny, 1826.

Gyroidina soldanii d'Orbigny.

Plate II, figs. 13 *a, b*.

Guroidini soldanii d'Orbigny, 1826, p. 278, No. 5, Modèles No. 36. Cushman, 1931, p. 38, pl. viii, figs. 3-8.

There are numerous specimens resembling the Recent example figured by Cushman (loc. cit., figs. 3 *a-c*) as a young form of *G. soldanii,* and others intermediate between this and the normal, adult form of this species. The typical adult form is in the Commonwealth Palaeontological Collection at Canberra from the Claremont No. 1 Bore at 300-350 feet.

Gyroidina soldanii d'Orbigny, var. **octocamerata** Cushman and G. D. Hanna.

Plate II, figs. 14 *a-c*.

Gyroidina soldanii d'Orb., var. *octocamerata* Cushman and G. D. Hanna, 1927, p. 223, pl. xiv, figs. 16-18. Cushman, 1935, p. 45, pl. xviii, figs. 4 *a-c*.

The specimens agree well with Cushman's figure of this form from the Upper Eocene (Ocala limestone) of Alabama, U.S.A. Cushman notes that

it also occurs in the Claiborne group as well as in the equivalent Eocene of Mexico and California. The types were from the Eocene of California.

The features distinguishing this from the well-known *G. soldanii* are its smaller size, (maximum diameter 0.50 mm.) and the eight chambers in the adult whorl. The Perth specimens attain a diameter of 0.41 mm. and are thinner-shelled than is usual in *G. soldanii.*

Genus **PULVINULINELLA** Cushman, 1926.

Pulvinulinella obtusa (Burrows and Holland), var. **westraliensis,** var. nov.

Plate III, figs. 1 *a-c.*

Pulvinulinella exigua (Brady), var. *obtusa* Cushman and Ponton, (non *Pulvinulina exigua,* var. *obtusa* Burrows and Holland), 1932, p. 71, pl. ix, figs. 9 *a-c.*

Test small, biconvex, the dorsal side less convex than the ventral, peripheral margin subacute and sometimes slightly lobulated; chambers few, distinct, usually six in the last-formed whorl; sutures distinct, on the dorsal side very oblique, almost straight, ventrally nearly radial and a little depressed, beginning from a small filled umbilicus; wall smooth, comparatively thick; aperture on the ventral side of the peripheral face, elongate, nearly parallel to the plane of coiling. Diameter up to 0.36 mm.; height to 0.25 mm.

Holotype of variety from King's Park Bore No. 2, 728 feet.

This form is common in the samples. It is closely related to the form described by Burrows and Holland (1897, p. 49, pl. ii, fig. 25) from the Lower Eocene of the Isle of Thanet, under the name of *Pulvinulina exigua* Brady, var. *obtusa.* My friend, Mr. F. Chapman, has kindly supplied me with a number of examples of var. *obtusa* from the type locality, Pegwell Bay, and these show it to belong to the genus *Pulvinulinella.* While it is probable that *Pulvinulina exigua* Brady should be placed in the same genus, the differences between the two forms, one described from Recent seas, in which it is usually found in very deep water, and the other known only from the Eocene, in deposits laid down in moderately shallow water, are, to the writer's mind, conclusive evidence that they are specifically distinct and they are here dealt with accordingly. The Eocene specimens figured by various writers as *P. exigua* do not show a close resemblance to the figures given by Brady (1884, pl. ciii, figs. 13, 14), although they do to *P. obtusa.* Burrows and Holland state that in *P. exigua,* the acute lobulated periphery is remarkably constant, while the obtuse periphery and more compact habit are no less constant characters in the var. *obtusa.*

The Western Australian form differs from the examples of *P. obtusa* from Pegwell Bay in having the dorsal side only slightly convex, while the ventral side is strongly so. The margin is subacute, compared with the rounded margin of *P. obtusa.* In other respects they are similar.

A form closely related to the present one is that described by Chapman, Parr, and Collins (1934, p. 565, pl. ix, figs. 19 *a-c*) as *? Pulvinulinella tenuimarginata,* from the Lower Miocene of Victoria. This has a thinner, sharply-margined test and is possibly derived from the Western Australian form.

Genus **EPISTOMINA** Terquem, 1883.

Epistomina elegans (d'Orbigny).

Rotalia (*Turbinulina*) *elegans* d'Orbigny, 1826, p. 276, No. 54.
Epistomina elegans (d'Orb): Cushman, 1927, p. 182, pls. xxxi, xxxii.

Small, but otherwise typical examples occur.

Genus **SIPHONINA** Reuss, 1849.

Siphonina sp.

Plate III, fig. 2.

One small, broken example of a species of *Siphonina*, which could not be determined, was met with.

Genus **ANOMALINA** d'Orbigny, 1826.

Anomalina perthensis, sp. nov.

Plate III, fig. 3 *a-c*.

Test of about two and a half coils, almost bilaterally symmetrical with broadly rounded periphery, the dorsal side slightly evolute and with all of the whorls visible, chambers numerous, up to twelve in the last-formed whorl, chamber wall smooth on dorsal side, coarsely perforate on ventral side; sutures broad and sometimes limbate and raised, gently recurved, the amount of curvature being greater on the dorsal side than on the ventral; aperture a narrow curved opening at the base of the last chamber. Diameter up to 0.37 mm.; thickness to 0.13 mm.

Holotype from King's Park Bore No. 2, 728 feet.

This species resembles *A. bilateralis* Cushman, from the Lower Oligocene of U.S.A., but a comparison with examples of Cushman's species shows that the two are distinct. *A. perthensis* is distinguishable by its much smaller size (one-third of that of *A. bilateralis*), thicker test, which is quite different in edge view, and the invariably smooth wall of the chambers on the dorsal side.

Anomalina westraliensis, sp. nov.

Plate III, figs. 4 *a-c*.

Test plano-convex, consisting of about one and a half whorls, involute on the ventral side, very slightly evolute on the dorsal; ventral side flattened, sometimes slightly concave, dorsal side broadly convex; periphery rounded in young specimens, becoming sub-acute in the adult, lobulated in the later part of the test; chambers comparatively few, 8 in the last-formed whorl; sutures recurved, limbate except in the last two or three chambers, slightly depressed on the ventral side, on the dorsal side flush, sometimes raised; wall calcareous, very coarsely perforated in the adult; aperture an arched slit at the inner margin of the last chamber. Diameter to 0.7 mm.; thickness to 0.2 mm.

Holotype from King's Park Bore No. 1, 770 feet.

This species shows an interesting development, the early stages being almost bilaterally symmetrical with a rounded peripheral margin, as in the more typical species of *Anomalina*. The plano-convex test and sub-acute margin of the test in the adult are reminiscent of *Cibicides*.

Genus **CIBICIDES** Montfort, 1808.

Cibicides lobatulus (Walker and Jacob).

Nautilus lobatulus Walker and Jacob, 1798, p. 642, pl. xiv, fig. 36.
Cibicides lobatulus (W. & J.): Cushman, 1931, p. 118, pl. xxi, figs. 3 *a-c*; 1935, p. 52, pl. xxii, figs. 4-6.

Typical examples occur. Cushman (1935, op. cit.), in recording this species from the Upper Eocene of the United States, notes it is common in the various members of the earlier Tertiary.

Cibicides pseudoconvexus, sp. nov.

Plate III, figs. 5 *a-c*.

Test plano-convex to concavo-convex, the ventral attached side flattened or concave, the dorsal side strongly convex, periphery sub-acute and frequently with a slight keel, particularly in the earlier part of the shell; chambers fairly numerous, 5 in the last-formed whorl, increasing rapidly in size and height as added, all chambers visible from the ventral side, only those of the last-formed whorl visible from the dorsal side; sutures distinct, strongly depressed and radial on the dorsal side, on the ventral side slightly depressed, recurved; wall smooth and finely perforate; aperture at the periphery and extending over and along the inner margin of the chamber on the ventral side. Diameter up to 0.7 mm.; thickness to 0.4 mm.

Holotype from King's Park Bore No. 1, 770 feet.

This species is common in the samples. It is closely related to the Upper Cretaceous *C. convexus* (Reuss), but the chambers increase more rapidly in size, the earlier chambers are keeled, and the shell wall is finely perforate, while that of *C. convexus* is coarsely perforate.

Cibicides pseudoungerianus (Cushman).

Truncatulina ungeriana Brady (non *Rotalina ungeriana* d'Orbigny), 1884, pl. xciv, figs, 9 *a-c*.
T. pseudoungeriana Cushman, 1922, pp. 97, 136, pl. xx, fig. 9.
Cibicides pseudoungerianus (Cush): Cushman, 1931, p. 123, pl. xxii, figs. 3-7; 1935, p. 52, pl. xxiii, figs. 1 *a-c*.

There are several fairly typical examples. This species has a geological range of from Eocene to Recent. It was described from the Lower Oligocene of the United States.

Cibicides umbonifer, sp. nov.

Plate III, fig. 6 *a-c*.

Test plano-convex, flattened on the ventral face, periphery subacute and limbate; chambers 10 to 12 in the last-formed whorl, those of the earlier whorls usually obscured by the thickening of the surface; sutures distinct in the last-formed whorl, gently recurved on both sides of the test, flush with the surface on the dorsal side, generally depressed on the ventral side; umbilical region filled with a conspicuous plug of clear shell material, which is flush with the chambers; surface on the ventral side distinctly perforate, on the dorsal side smooth and very finely perforate; aperture peripheral extending over to the ventral side of the test, with a slight lip. Diameter up to 0.5 mm.; thickness to 0.2 mm.

Holotype from King's Park Bore No. 2 728 feet.

This species is common in the samples. It is related to *C. pseudoungerianus*, but is proportionately thicker, has limbate sutures on the ventral side, and a larger and flush umbilical boss on the dorsal side. The outside whorl is also narrower than that of *C. pseudoungerianus*.

FAMILY **CHILOSTOMELLIDAE.**

Genus **PULLENIA** Parker and Jones. 1862.

Pullenia quinqueloba (Reuss).

Nonionina quinqueloba Reuss, 1851, p. 47, pl. v, fig. 31.
Pullenia quinqueloba (Reuss): Plummer, 1926, p. 136, pl. viii, figs. 12 *a, b*.

Typical examples of this widely-distributed species were met with.

FAMILY **ORBULINIDAE.**

Genus **GLOBIGERINA** d'Orbigny, 1826.

Globigerina triloba Reuss.

Globigerina triloba Reuss, 1850, p. 374, pl. xlvii, figs. 11 *a-e*.

This species was described from the Miocene of the Vienna Basin. The present specimens agree with examples I have from Baden, near Vienna.

Globigerina inflata d'Orbigny.

Globigerina inflata d'Orbigny, 1839a, p. 134. pl. ii, figs. 7-9. Brady, 1884, p. 601, pl. lxxix, figs. 8-10. Nuttall, 1935, p. 130.

Small specimens occur. This species, which exists at the present day in every ocean, is stated by Nuttall (loc. cit.) to be common in the Upper and Middle Eocene of Mexico and in the Upper Eocene of Trinidad. Nuttall's record was from the Upper Eocene of Venezuela.

Globigerina orbiformis Cole.*

Plate III, figs. 7 *a, c*.

Globigerina orbiformis Cole, 1927, p. 33, pl. v, fig. 7.

Typical examples occur. Dr. J. A. Cushman has kindly supplied me with specimens of this species from some of Dr. Cole's type material from the Middle Eocene (Guayabal Formation) at Guayabal, Mexico. It appears to be closely related to *G. inflata*, with which it occurs.

Genus **GLOBOROTALIA** Cushman, 1927.

Globorotalia chapmani, sp. nov.

Plate III, figs. 8, 9 *a, b*.

Test biconvex, oval, the dorsal surface more convex than the ventral, which is umbilicate; periphery lobulated, peripheral margin rounded; chambers comparatively few, not more than five in the last-formed whorl, each

*Dr. H. Thalmann has since informed the writer that *G. orbiformis* is identical with the earlier-described *G. mexicana* Cushman (1925, Contr. Cushman Lab., vol. I, p. 6, pl. i, fig. 8), from the Upper and Middle Eocene of East Mexico. This opinion is the result of several years experience in Mexico, during which Dr. Thalmann examined much material from the Guayabal (now known as the Tempoal) Formation.

much larger than its predecessor; sutures depressed, not limbate, gently recurved on both sides of the test; wall smooth and punctate, with a silvery lustre; aperture an elongate slit with a slight lip, opening at the base of the last-formed chamber into the umbilical depression. Length up to 0.65 mm.

Holotype from King's Park Bore No. 1, 755 feet.

This species belongs to the group of *G. hirsuta* (d'Orbigny) and is perhaps nearest to *G. hirsuta,* which has typically only four chambers to a whorl and with the sutures on the ventral side radial.

FAMILY **NUMMULITIDAE.**

Genus **NONION** Montfort, 1808.

Nonion novozealandicus Cushman.

Nonion novozealandicus Cushman, 1936, p. 66, pl. xii, figs. *a, b.*

This species was recently described by Dr. Cushman from the Lower Oligocene of Motutara Point, Kawhia Harbour, New Zealand. In the King's Park bore samples, examples are common. They attain a diameter of 0.5 mm. and a thickness of 0.2 mm., and so are proportionately slightly thinner than the dimensions given by Cushman. Many of the examples I have from the type locality show a similar variation.

SUPER-FAMILY **AMMODISCOIDEA.**

FAMILY **AMMODISCIDAE.**

Genus **AMMODISCUS** Reuss, 1861.

Ammodiscus sp. aff. **incertus** (d'Orbigny).

There are two fragments, the larger measuring 1.9 mm. in length and consisting of portion of three whorls, which appear to be d'Orbigny's species.

FAMILY **RHIZAMMINIDAE.**

Genus **BATHYSIPHON** M. Sars, 1872.

Bathysiphon sp.

Plate III, fig. 10.

Fragments of a species of *Bathysiphon* are common. They are generally ovate in section, and attain a diameter of 2 mm. The central cavity is about one-third of the diameter. The tube in some specimens is transversely constricted or corrugated and the surface is usually coated with a black film. The wall consists mainly of siliceous sand and a small proportion of broken sponge spicules, with abundant siliceous cement. The species is probably new, but more and better material is needed to decide this.

FAMILY **OPHTHALMIDIIDAE.**

Genus **CORNUSPIRA** Schultze, 1854.

Cornuspira involvens (Reuss).

Operculina involvens Reuss, 1850, p. 370, pl. xlvi, fig. 2.
Cornuspira involvens (Reuss): Cushman, 1929, p. 80, pl. xx, figs. 6, 8.

There is one typical example.

FAMILY MILIOLIDAE.

Genus QUINQUELOCULINA d'Orbigny, 1826.

Quinqueloculina seminulum (Linné).

Serpula seminulum Linné, 1767, p. 1264.

Quinqueloculina seminulum (Linné): Cushman, 1929, p. 24, pl. ii, figs. 1, 2. Cushman and Cahill, 1933, p. 9, pl. ii, figs. 2 *a-c*.

Small specimens occur. The smooth species of *Quinqueloculina* are difficult to separate without abundant specimens and sections, and identifications based on exterior characters are therefore unsatisfactory. The three species here recorded have been so identified, as I have not been able to obtain good sections. Forms very similar to the present specimens have been identified from the Eocene of the United States as *Q. seminulum* (Stadnichenko, Journ. Pal., vol. i, 1927, p. 226, pl. xxxviii, fig. 28), *Q. yeguaensis* (Weinzierl and Applin, Journ. Pal., vol. iii, 1929, p. 393, pl. xliv, fig. 4) and *Q. laevigata* d'Orb. (Cushman, 1935, p. 11, pl. ii, figs. 13-15).

Quinqueloculina vulgaris d'Orbigny.

Quinqueloculina vulgaris d'Orbigny, 1826, p. 302, No. 33. Cushman, 1929, p. 25, pl. ii, figs. 3 *a-c*.

There are several small examples, the largest measuring 0.45 mm. in length.

Quinqueloculina venusta Karrer.

Quinqueloculina venusta Karrer, 1868, p. 147, pl. ii, fig. 6.

Miliolina venusta (Karrer): Brady, 1884, p. 162, pl. v, figs. 5, 7.

There are a few small examples with blunter angles than those figured by Brady.

FAMILY LITUOLIDAE.

Genus CYCLAMMINA Brady, 1876.

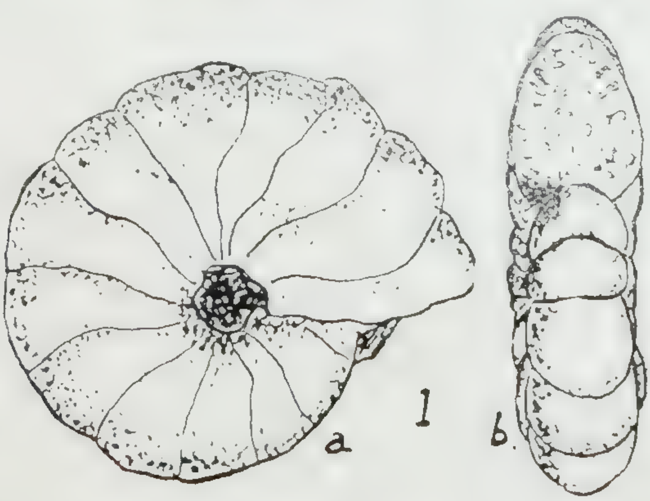
Cyclammina incisa (Stache).

Text-fig. 1.

Haplophragmium incisum Stache, 1864, p. 165, pl. xxi, fig. 1.

Cyclammina incisa (Stache): Chapman, 1926, p. 29, pl. ii, fig. 1. Cushman and Barbat, 1932, p. 32, pl. v, figs. 2 *a, b*.

Test much compressed, umbilicate; chambers eight to ten in the last-formed whorl, somewhat irregular in size; sutures slightly depressed, a



Text-figs. 1 *a, b*. *Cyclammina incisa* (Stache). Bore No. 1, 530 ft. *a*, side view; *b*, peripheral view. × 26.

little curved, nearly radial; wall finely arenaceous, rather smoothly finished. Diameter up to 2.1 mm.

This species was described from the Lower Oligocene of Whaingaroa Harbour, New Zealand. It is common in the King's Park bore samples. The largest specimen measures 2 mm. in diameter, but generally they do not exceed 1.2 mm.

FAMILY **TEXTULARIIDAE.**

Genus **SPIROPLECTAMMINA** Cushman, 1927.

Spiroplectammina sp.

Plate III, figs. 12 *a, b.*

There are several examples of a small species of this genus, but insufficient for specific determination. Megalospheric and microspheric specimens are present. In the former, the coil forms about one-third of the test. The remainder of the test is parallel-sided and consists of about eight chambers with slightly depressed sutures, the height of each chamber being about half the length. The test is sub-rhomboidal in end view; the wall is composed of fine sand grains, with a good deal of cement, resulting in a smoothly-finished surface. The microspheric form begins with a much smaller coil and the test consequently gradually increases in width instead of having the sides parallel as in the megalospheric form. Both forms attain a length of 0.35 mm. and a width of 0.16 mm.

FAMILY **VERNEUILINIDAE.**

Genus **GAUDRYINA** d'Orbigny, 1839.

(?) **Gaudryina subquadrata** Cushman.

G. subquadrata was described by Cushman (1933, p. 2, pl. i, figs. 1 *a-c*) from the Upper Eocene of South Carolina. It is a very elongate tapering species, almost rectangular in section, and with a very short triserial portion. The broader faces are distinctly concave. The species attains a length of 1 mm.

The specimens from the King's Park borings are doubtfully referred to this species as the initial end is, in every case, broken off, but in other respects they agree with Cushman's description and figures. The largest specimen is 0.75 mm. long, 0.28 mm. wide, and 0.18 mm. thick.

THE AGE OF THE SAMPLES.

The assemblage of foraminifera includes a number of long-ranging species, but with these are associated a number of more restricted forms, or forms closely related to species, mainly North American, with a limited range. The ranges of species previously described will be found in the table showing the distribution of foraminifera in the bores.

Frondicularia mucronata is typically Upper Cretaceous, but appears to occur in the Lower Eocene of Texas. *Bolivinopsis eocenica, Dentalina colei,* and *Gyroidina soldanii,* var. *octocamerata* are American Eocene species. *Discorbis assulatus* is confined to the Upper Eocene of the United States, while *Globigerina orbiformis* is known only from the Middle Eocene of Mexico.

Vaginulina subplumoides, sp. nov., is near *V. plumoides*, from the Lower Eocene of Texas. *Gümbelina venezuelana*, a new variety of which is described, is known only from the Upper Eocene of Venezuela. *Pulvinulinella obtusa*, var. *westraliensis*, nov., appears to be present in the Eocene of the United States.

With these is *Valvulineria sculpturata*, a very distinct species, recently described from the Lower Oligocene of the United States. *Angulogerina subangularis*, sp. nov., is closely related to, but more primitive than *A. vicksburgensis*, also confined to the Lower Oligocene of the United States.

On this evidence there can be little doubt that the faunule is definitely of Eocene age. The presence of species identical with or similar to other restricted Upper Eocene forms, with a slight Lower Oligocene element, indicates that the beds are high in the Eocene and they are accordingly considered to be of Upper Eocene age.

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APPENDIX.

By the courtesy of the Commonwealth Geological Adviser, Dr. W. G. Woolnough, and the Commonwealth Palaeontologist, Miss Irene Crespin, B.A., who have made available the slides of foraminifera in the Commonwealth Palaeontological Collection at Canberra from other borings in the Perth area, the following additional records of the new species described in this paper are given.

Lagena perthensis

Zoological Gardens Bore—615ft.

L. terrilli

Claremont No. 1 Bore—100-150ft., 250-300ft., 300-350ft., 750-850ft. Zool. Gardens Bore—615ft.

Buliminella westraliensis

Claremont No. 1 Bore—92-100ft., 100-150ft., 150-200ft., 200-250ft., 750-850ft. Zool. Gardens Bore—960ft.

Angulogerina subangularis

Claremont No. 1 Bore—100-150ft., 150-200ft., 200-250ft., 250-300ft.

Bolivinopsis crespinae

Claremont No. 1 Bore—300-350ft.

Heronallenia pusilla

Claremont No. 1 Bore—300-350ft., 750-850ft.

Ceratobulimina westraliensis

Claremont No. 1 Bore—100-150ft.

Pulvinulinella obtusa, var. *westraliensis*

Claremont No. 1 Bore—92-100ft., 150-200ft.

Anomalina perthensis

Claremont No. 1 Bore—100-150ft.

Anomalina westraliensis

Zool. Gardens Bore—615ft.

Cibicides pseudoconvexus

Claremont No. 1 Bore 150-200ft., 250-300ft., 300-350ft.

C. umbonifer

Claremont No. 1 Bore 92-100ft., 100-150ft., 150-200ft., 250-300ft., 300-350ft., 750-850ft. Zool. Gardens Bore -217ft., 615ft., 960ft.

EXPLANATION OF THE PLATES.

Plate I.

Figs. 1 *a*, *b*. *Lenticulina* sp. Bore No. 1, 120 ft. *a*, side view; *b*, front view. × 39.

„ 2 *a*, *b*. *L.* (*Robulus*) *warmani* (Barbat and Estorff). Bore No. 2, 230 ft. *a*, side view; *b*, front view. × 39.

„ 3. *Marginulina* sp. Bore No. 2, 230 ft. × 39.

„ 4. *Vaginulina* sp. Bore No. 2, 385 ft. × 39.

„ 5. *Marginulina gladius* Philippi. Bore No. 1, 120 ft. × 39.

„ 6. *M. subbullata* Hantken. Bore No. 1, 120 ft. × 39.

„ 7. **Vaginulina subplumoides**, sp. nov. Holotype. Bore No. 2, 385 ft. × 39.

„ 8. *Dentalina colei* Cushman and Dusenbury. Bore No. 1, 120 ft. × 39.

„ 9. *D. spinulosa* (Montagu). Bore No. 1, 770 ft. × 39.

„ 10. *Nodosaria radicula* (Linné). Bore No. 1, 120 ft. × 39.

„ 11. **Pseudoglandulina clarkei**, sp. nov. Holotype. Bore No. 2, 606 ft. × 39.

„ 12. *Frondicularia mucronata* Reuss. Bore No. 2, 430 ft. × 39.

„ 13. **Lagena luciae**, sp. nov. Holotype. Bore No. 2, 555 ft. × 78.

„ 14. **L. perthensis**, sp. nov. Holotype. Bore No. 2, 430 ft. × 78.

„ 15 *a*, *b*. **L. terrilli**, sp. nov. Holotype. Bore No. 2, 430 ft. *a*, side view; *b*, apertural view. × 39.

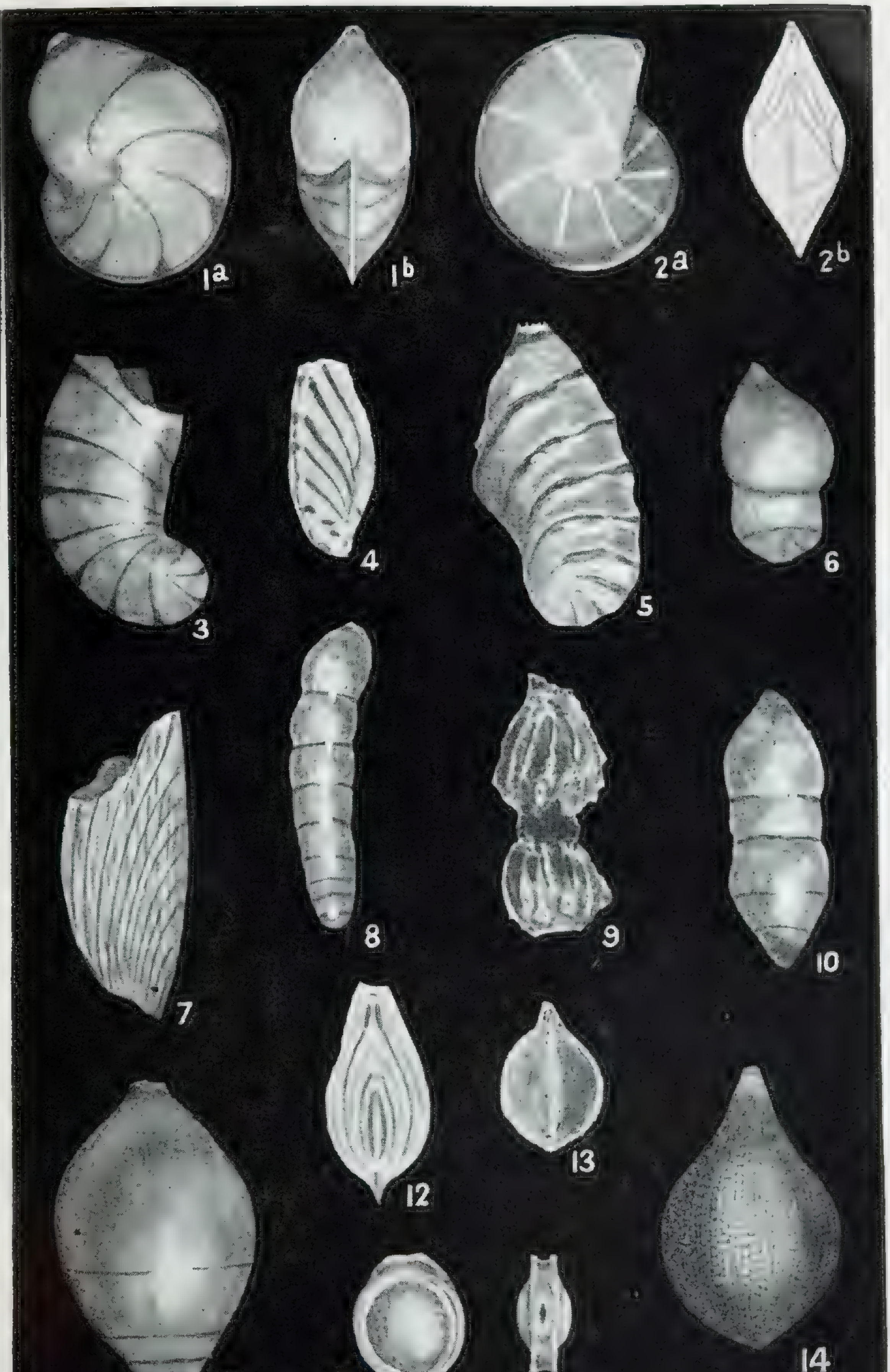

PLATE I.

Plate II.

Figs. 1 *a, b*. *Guttulina irregularis* (d'Orbigny). Bore No. 2, 230 ft. *a*, side view; *b*, basal view. × 26.

" 2 *a, b*. *Globulina rotundata* (Bornemann). Bore No. 1, 120 ft. *a*, side view; *b*, basal view. × 26.

" 3, 4. **Buliminella westraliensis**, sp. nov. 3, Holotype. Bore No. 1, 755 ft. 4, Bore No. 2, 728 ft. Both × 78.

" 5. *Robertina* sp. Bore No. 1, 755 ft. × 78.

" 6 *a, b*. **Angulogerina subangularis**, sp. nov. Holotype. Bore No. 1, 770 ft. *a*, side view; *b*, apertural view. × 78.

" 7. *Cassidulina* sp. Bore No. 1, 755 ft. × 78.

" 8 *a, b*. Gümbelina venezuelana Nuttall, var. **rugosa**, var. nov. Holotype. Bore No. 1, 770 ft. *a*, side view; **b**, edge view. × 78.

" 9 *a-c*. *Discorbis assulatus* Cushman. Bore No. 2, 555 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.

" 10 *a-c*. *Valvulineria sculpturata* Cushman. Bore No. 2, 728 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.

" 11 *a-c*. **Heronallenia pusilla**, sp. nov. Holotype. Bore No. 2, 728 ft. *a*, dorsal view; **b**, ventral view; *c*, edge view. × 78.

" 12 *a-c*. **Ceratobulimina westraliensis**, sp. nov. Holotype. Bore No. 2, 606 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 52.

" 13 *a, b*. *Gyroidina soldanii* d'Orbigny. Bore No. 2, 230 ft. × 78.

" 14 *a-c*. *G. soldanii*, var. *octocamerata* Cushman and G. D. Hanna. Bore No. 1, 755 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.


1a
2a
3
4
5
6b
6a
1b
2b
7
8a
8b
9a
10a
10b
10c
9b
11a
12a
9c
11b
12c
12b
11c
13a
13b
14a
14b
14c

PLATE II.

Plate III.

Figs. 1 *a-c*. *Pulvinulinella obtusa* (Burrows and Holland), var. **westraliensis**, var. nov. Holotype. Bore No. 2, 728 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.

,, 2. *Siphonina* sp. Bore No. 1, 492 ft. × 117.

,, 3 *a-c*. **Anomalina perthensis**, sp. nov. Holotype. Bore No. 2, 728 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.

,, 4 *a-c*. **A. westraliensis**, sp. nov. Holotype. Bore No. 1, 770 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 39.

,, 5 *a-c*. **Cibicides pseudoconvexus**, sp. nov. Holotype. Bore No. 1, 770 ft. *a*, ventral view; *b*, dorsal view; *c*, edge view. × 39.

,, 6 *a-c*. **C. umbonifer**, sp. nov. Holotype. Bore No. 2, 728 ft. *a*, ventral view; *b*, dorsal view; *c*, edge view. × 78.

,, 7 *a-c*. *Globigerina orbiformis* Cole. Bore No. 1, 755 ft. *a*, dorsal view; *b*, ventral view; *c*, edge view. × 78.

,, 8, 9 *a, b*. **Globorotalia chapmani**, sp. nov. Bore No. 1, 755 ft. 9 *a, b*, Holotype. *a*, ventral view; *b*, edge view. 8. Dorsal view of another specimen. All × 78.

,, 10. *Bathysiphon* sp. Bore No. 1, 563-573 ft. × 13.

,, 11 *a, b*. **Bolivinopsis crespinae**, sp. nov. Holotype. Bore No. 2, 728 ft. *a*, side view; *b*, edge view. × 117.

,, 12 *a, b*. *Spiroplectammina* sp. Bore No. 2, 728 ft. *a*, side view; *b*, apertural view. × 78.

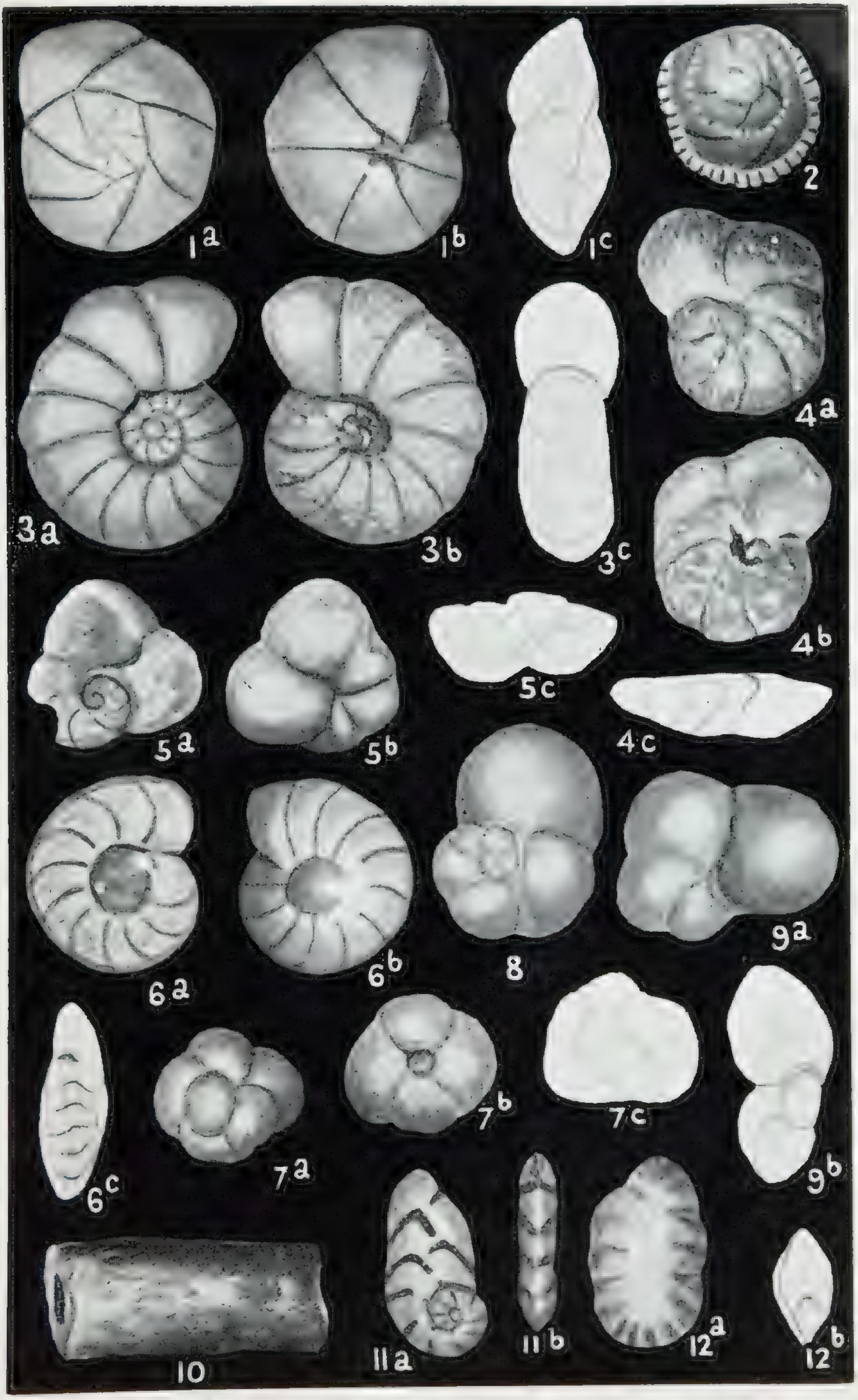
1a
1b
1c
2
3a
3b
3c
4a
4b
4c
5a
5b
5c
6a
6b
6c
7a
7b
7c
8
9a
9b
10
11a
11b
12a
12b

PLATE III.

9.—THE ASCORBIC ACID CONTENT OF SOME WESTERN AUSTRALIAN FRUITS

(*AS INDICATED BY TITRATION WITH PHENOL-INDO-2:6-DICHLOROPHENOL*).

By H. E. Hill, A.I.C., A.A.C.I.

Read 8th March, 1938; Published 1st July, 1938.

This paper details the results of determinations of ascorbic acid (vitamin C) in a number of Western Australian fruits during the season 1937-38. The object of the investigation was to make a rapid survey of the principal fruits which are grown in the State, firstly to discover whether the values found are comparable with those reported elsewhere for the same fruits, and, secondly, to record values for certain fruits which do not appear to have been examined elsewhere. In all cases, except where otherwise stated, fruits freshly gathered on the day on which the analyses were made have been utilised. Choice, ripe specimens only were used, and the analyses were completed as quickly as possible.

It is recognised that each individual kind of fruit has a range of values of ascorbic acid content over which variation occurs. For this reason it is not claimed for these results, obtained as they are from two or three and in some cases one sample only, that they should serve as any more than an indication for reference, or for future use in determining the ranges and means.

Method.—During recent years a number of workers have made determinations of the ascorbic acid content of various biological materials, particularly vegetable products such as fruits, as well as extracts of animal tissues. This work has been stimulated by findings regarding the importance of vitamin C in certain conditions and disorders of the human subject in addition to the rôle which it plays as the antiscorbutic factor in nutrition. It is recognised that the most accurate method of determining the ascorbic acid is the biological assay method of feeding to animals such as guinea pigs, in which the effects of the substance under examination are compared with those of a prepared food containing a known amount of the vitamin. This method is long and tedious and, moreover, cannot be carried out without the resources of an animal laboratory, which are not available in Western Australia.

The determination of ascorbic acid has been considerably facilitated, however, by the introduction by Tillmans and his associates (1) and development by Birch, Harris & Ray (3) of a simple titration procedure taking advantage of the reducing power of the acid and using the oxidation-reduction indicator phenol-indo-2:6-dichlorophenol. The method is supported by a considerable amount of animal assay work and, with minor modifications, has come into extensive use. Bessey & King (4) and others have pointed out that ascorbic acid is not an absolutely specific reducing agent for the indicator, as other substances exist in biological materials, such as glutathione, cysteine, phenolic compounds, etc., which have a lower reduction potential and are, therefore, a possible source of interference. The magnitude of the resultant error is greatest in materials with a low ascorbic acid content, such as animal tissues and extracts which, moreover, contain more

of the interfering substances. With vegetable tissues, particularly fruit juices and extracts, the percentage error is much less, being usually of the order of 2 to 3 per cent. The method, therefore, is well suited for a survey of this nature, involving only fruits, where an indication of the degree of the ascorbic acid content rather than the exact amount is required.

The method used in this work was essentially that described by Bessey & King (5). From one to six fruits, depending on the size, were used. The edible portion only was taken. A suitable quantity, usually 10 or 20 grams, was rapidly ground in a mortar with sand and 8 per cent. trichloroacetic acid, centrifuged, and the extract poured off, then ground with more acid and centrifuged again. The combined extracts were made to 50 ml and an aliquot of 10 or 20 ml taken for titration. A 0.05 per cent. solution of phenol-indo-2:6-dichlorophenol was run in until a definite pink colour was obtained. This preliminary titration gave the approximate amount of the dye required. A second titration was made by running in most of the quantity required and adding the remainder slowly, the whole titration usually being complete in two minutes. The conditions stressed by Harris (6), namely, removal of proteins by trichloroacetic acid, extraction with as little delay as possible and titration at an acid reaction in a time not exceeding two minutes, were thus all complied with.

The phenol-indo-2:6-dichlorophenol solution was standardised periodically against pure ascorbic acid (B.D.H.). The method of standardisation against the iodine titration of fresh lemon juice, advocated by Bessey & King, was also found satisfactory.

In the case of fruits yielding coloured extracts to trichloroacetic acid, such as mulberry, plum and fig, the modification by McHenry & Murray Graham (7) of the method described by Tillmans, Hirsch & Jackisch (2), involving titration in the presence of a layer of chloroform, which dissolves the red colour of the excess of dye but not the anthocyanins of the fruits, was used with success.

The results, giving in the following table, are arranged in approximately descending order of the ascorbic acid content, citrus fruits and tropical fruits, however, being separated from the others.

——	Locality.	Ascorbic acid. Mg. per gm.
Citrus Fruits.		
Orange (*Citrus sinensis* Osbeck)—		
Washington navel	Gosnells	0.49
		0.39
Valencia	Gosnells	0·68
		0.44
Mandarin orange (*Citrus nobilis* Lour var. *deliciosa* Swingle)	Gosnells	0.51
Lemon (*Citrus limonia* Osbeck)	Claremont ...	0.43
	Gosnells	0.33
	s.p.*	0.42
Kumquat (*Fortunella japonica* Swing)	South Perth ...	0.30
Grape fruit or pummelo (*Citrus maxima* Merr.) ...	Gosnells ...	0.33
Lime—New Caledonian (*Citrus aurantifolia* Swingle)	South Perth ...	0.26
Citron—Sport from orange (*Citrus medica* L.) ...	Claremont ...	0.24

*s.p.—Purchased from shops.

Note.—The botanical names are taken from L. H. Bailey's "Manual of Cultivated Plants."

——	Locality.	Ascorbic acid. Mg. per gm.
Miscellaneous Fruits.		
Banana passion fruit (*Passiflora mollissima* Bailey)	s.p.*	0.44
Passion fruit (*Passiflora edulis* Sims)	s.p.	0.24
	Osborne Park ...	0.24
Cape Gooseberry (*Physalis peruviana* L.)	s.p.	0.22
		0·21
Peach (*Prunus Persica* Sieb u Zucc.)—		
Early variety	s.p.	0.01
Elberta	Gosnells	0.17
Apricot (*Prunus Armeniaca* L.)	s.p.	0.06
Mulberry (*Morus nigra* L.)	Claremont ...	0.13
	Cottesloe ...	0.08
Rock-melon (*Cucumis Melo* L.)	Gosnells	0.10
Water-melon (*Citrullus vulgaris* Schrad)	Upper Swan ...	0.14
	Upper Swan ...	0.05
Plum (*Prunus domestica* L.)—		
Satsuma	Gosnells	0.07
	Karragullen ...	0.03
Nectarine (*Prunus Persica* Sieb u Zucc. var. *nucipersica* Schneid)	Karragullen ...	0.08
Grape (*Vitis vinifera* L.)—		
Xante currant	Claremont ...	0.03
Muscat Gordo Blanco	Claremont ...	0.04
Muscat of Alexandria	Claremont ...	0.05
Muscat Canon Hall (partly ripe)	South Perth ...	0.04
Sultana	Claremont ...	0.06
Black Prince	Claremont ...	0.05
Crystal	Cottesloe ...	0.02
Fig (*Ficus carica* L.)—		
Adam (cross)	South Perth ...	0.02
Adam	Cottesloe ...	0.02
Brown Turkey	Cottesloe ...	0.02
Smyrna	Applecross ...	0.03
Loquat (*Eriobotrya japonica* Lindl.)	Gosnells	*nil*
	s.p.	*nil*
Tropical Fruits.		
Guava—Large yellow (*Psidium Guajava* L.) ...	s.p.	1.10
Papaw (*Carica papaya* L.)	Carnarvon ...	0.98
Rock-melon—Honeydew variety (*Cucumis Melo* L. var. *inodorus* Waud.)	Carnarvon ...	0.21
Pineapple (*Ananas comosus* Merr.)	Carnarvon ...	0.19
Mango (*Mangifera indica* L.)	Carnarvon ...	0.13
Banana (*Musa paradisiaca* L. var. *sapientum* Kuntze)—		
Cavendish	Carnarvon ...	0.12
Sugar	Carnarvon ...	0.04
Plantain	Carnarvon ...	0.11
Golden Gros	Carnarvon ...	0.02

*s.p.—Purchased from shops.

Note.—The botanical names are taken from L. H. Bailey's "Manual of Cultivated Plants."

The values found for those fruits which have been examined elsewhere are seen to be well in accord with other reported results. The high values for guava and papaw are noteworthy, whilst those for the banana passion fruit, passion fruit and cape gooseberry, which do not appear in the literature as having previously been examined, indicate that these fruits are moderately good sources of ascorbic acid. Another fruit not noted pre-

viously is the mulberry which, although a very juicy fruit, is not a good source. Grapes and figs have a very low value. The complete absence of even a trace in the loquat is also an interesting result.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge the assistance of Mr. J. C. Hood, of the Government Chemical Laboratory, who made some of the chemical determinations, and also to thank Dr. E. S. Simpson (Government Mineralogist and Analyst) for permission to publish these results. Thanks are also due to Mr. G. B. Barnett (Tropical Adviser, Department of Agriculture), Mr. E. T. Morgan (Inspection of Potatoes Branch, Department of Agriculture), and Mr. T. G. Bowman, of Gosnells, and others for samples of fruits, and to Mr. G. R. W. Meadly (Acting Government Botanist) for assistance with the botanical names.

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(1) 1932—Tillmans, J., Hirsch, P. & Hirsch, W.: *Z. Untersuch Lebens*: 1932.**63**.1. Abstract Analyst 1932.57.260.

(2) 1932—Tillmans, Hirsch & Jackisch: *Z. Untersuch Lebens*: 1932.**63**.241. Abstract Analyst 1932.57.396.

(3) Birch, Harris & Ray: *Biochem. J.*, 1933. **27**, I., 590.

(4) Bessey and King: *J. Biol. Chem.*, 1933, **103**, 687.

(5) Bessey and King. *Id.*, 1933, **103**, 690.

(6) Harris: *5th Internat: Tech. & Chem. Congress Agricult. Industries.*

(7) McHenry & Murray Graham: *Biochem. J.*, 1935, **29**, II., 2013.

Government Chemical Laboratory, Perth,
1st March, 1938.

10.—CONTRIBUTIONS TO THE MINERALOGY OF WESTERN AUSTRALIA.

Series XI.

By EDWARD S. SIMPSON, D.Sc., B.E., F.A.C.I.

Read: 10th May, 1938; Published: 12th August, 1938.

CONTENTS.

(1)—ANAUXITE, RAVENSTHORPE*, S.W.

The name anauxite was originally given to a clay mineral from Bilin, Czechoslovakia, by Breithaupt in 1838. Hintze in his monumental "Handbuch" gives it a scant three lines amongst a number of non-specific hydrous silicates. Doelter gives it a little more space but classifies it with cimolite, another indefinite mixture. In recent years, however, the name has been revived in the United States, and given specific rank with monoclinic crystallisation and the constitution $2H_2O.Al_2O_3.3SiO_2$, which differs only from that of kaolinite, nacrite, dickite and metahalloysite, by the addition of one molecule of silica. It forms typically the final product of the weathering or hydrothermal alteration of biotite. In view of its origin there is a doubt whether the third molecule of silica is combined with the other constituents or exists uncombined, but in intimate admixture, as chalcedony or opal.

An opportunity to examine this point came when a specimen of typical anauxite was sent me from Ravensthorpe. It consisted of a rather friable mass of soft, creamy white scales which reach a maximum diameter of four millimetres. They have a hardness of 1, are opaque except in thin flakes under the microscope, and have a pearly lustre. The composition given below indicates that they are pseudomorphous after titaniferous biotite. The second column gives the true composition of the clay mineral after rejecting chalcedony and rutile, in which form all the titanium was found to be present.

*Lat. 33° 31′. S., Long. 120° 3′. E.

Anauxite, Ravensthorpe and Bilin.

—	Ravensthorpe. Original.	Ravensthorpe. Recalculated.	Ravensthorpe. Molecules.	Bilin Type.
SiO_2, free	16·86	...	...	...
SiO_2, combined ...	32·28	40·90	681	50·75
Al_2O_3	26·05	33·00	324	33·34
Fe_2O_3	2·37	3·00	12·5	2·45
FeO, MnO	nil	nil	...	...
MgO	·56	·69	17	·27
CaO	·08	·10	2	·32
Na_2O	1·36	1·72	28	...
K_2O	·16	·20	2	...
H_2O + ...	13·72	17·38	965	11·38
H_2O—	2·04	2·58	143	1·26
TiO_2	4·09	...	...	...
P_2O_5	nil	...	...	...
Total	99·57	99·57	...	99·77

Analysts: H. P. Rowledge. W. P. Smirnoff.

It will be noticed that only two molecules of silica out of three in the Ravensthorpe mineral were combined, and after rejecting that present as chalcedony or opal, the recalculated composition gives the normal ratio for kaolin and halloysite of 1 to 2 for $Al_2O_3 + Fe_2O_3$ to SiO_2. The water percentage is nearer that of halloysite than kaolinite. Some of the soda is probably adsorbed, as the underground waters at Ravensthorpe are more or less saline. These facts do not support the contention that anauxite is an independent species.

References: 1896. Hintze, H.B.d.Mineralogie, 2 p. 1828.
1917. Doelter, H.B.d.Mineralchemie, 2(2), p. 32, 39, 123-4.
1928. Allen, *Amer.Minl.*13, p. 145-155.
1937. Gruner, Idem, 22, p. 855-860.
1938. Machatschki, Idem, 23, p. 117-118.

(2) AXINITE, WELD RANGE*, Mur.

In 1937 a prospector (L. M. Ryan) collected a number of fine specimens of axinite from a vein in Precambrian amphibolite somewhere in the Weld Range. The only associated mineral in the vein appears to be quartz, which was in minor amount, and of later growth, often well crystallised round the final cavities.

The enclosing rock is a coarse grained amphibolite consisting largely of a hornblende with extinction angle 20°, and γ, bluish green ; β, bottle green to yellowish green ; α, very pale yellow. Much plagioclase is present, with a fair amount of zoisite, some ilmenite and a little quartz. This rock is a typical newer, intrusive, amphibolite. Some boulders of an older fine grained amphibolite were picked up in the immediate vicinity.

*Lat. 27° 0′. S., Long. 117° 30′. E.

The axinite is in pure masses up to several pounds in weight, and is of two types. One is massive or microgranular, with G 3.19, and low translucency, about 1 mm. for bright diffused daylight. These characters indicate the prevalence of fluid inclusions. This type appears to be characteristic of the earlier stage of growth but growths from it are more or less well crystallised, with G 3-25 and 3.26, and translucency increased to 5 mm. Both types have a resinous lustre, and vary in colour from greyish white to a medium grey, with at times a slight purplish tint, near Ridgway 69⁴d. Many of the better crystallised pieces show groups of two or three adjacent faces not easy to correlate with recorded data, but recognised in three cases to be combinations of *Msr*, *Mrb* and *Msrbf*. The latter was a rather perfect crystal of 2·2 grammes, which yielded good measurements for the following faces in order of relative sizes.

$$M^1M^2rsb^1b^2f$$

M, $1\bar{1}0$ r, $1\bar{1}\bar{1}$ s, $\dot{2}01$ b, 010 f, 011

The refractive indices measured were Ng, 1·685; Np, 1·677.

A chemical analysis has yielded the following results :—

Axinite, Weld Range.

SiO_2	B_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	CaO
42·42	6·07	17·46	1·47	6·68	3·01	20·09
MgO	TiO_2	H_2O +	Alks.	Total.	G	Analyst
1·50	·12	1·93	nil	100·75	3·26	J. N. A. Grace

This is very close in composition to the original axinite from Bourg d'Oisans in France, and to that at Talbot Bay near Yampi Sound. The analytical figures yield the formula: 1·21 H_2O. 2·00 (Fe,Mn,Mg,Ca)O. 4·04 CaO. 2·04 $(Al,Fe)_2O_3$. 0·99 B_2O_3. 8·00 SiO_2.

The excess of water is doubtless due to fluid inclusions.

Reference: 1930. Simpson *Jour. Roy. Soc. W.A.*, Vol. 16, p.26–7.

(3) BEIDELLITE, BANGEMALL*, N.W.

Mr. F. G. Forman, Government Geologist, visited the Lyons Valley in 1937, and whilst inspecting McCarthy's old gold diggings 12 miles N.W. of Bangemall, noticed a bright yellow mineral in the auriferous quartz which he submitted to me for examination. If proved to be closely related to, if not identical with, beidellite, a clay mineral first found at Beidell in Colorado in 1925.

The Bangemall mineral forms thin (1 mm.) crusts, which on the surface are smooth or minutely mammilated, and occur on the numerous cracks and cavities in a very ferruginous quartz. It is bright ochre yellow in colour, has a specific gravity of 2·40, hardness 1, and mean refractive index 1·544. Under the microscope it is scaly in structure, translucent and highly birefringent.

*Lat. 24° 18′ S., Long. 116° 55′ E.

Some carefully selected mineral was analysed with the following results :—

—	Bangemall mineral.		Type Beidellite.	Type Montmorillonite.
	Per cent.	Mols.	Per cent.	Per cent.
SiO_2	45·92	765	47·28	48·60
Al_2O_3	22·02	216	20·27	20·03
Fe_2O_3	7·53	47	8·68	1·25
MgO	5·15	128	·70	5·40*
CaO	trace	...	2·75	1·72
Na_2O	·60	10	·97	present
K_2O	·80	8	trace	present
H_2O+	10·23	567	19·72	21·52
H_2O-	8·17	454	...	...
	100·42		100·37	98·52
Nm	1·544		1·536	1·527
Analyst	C. R. Le Mesurier		Larsen and Wherry	E. V. Shannon

* Includes MnO, 0·16.

No sulphate or chloride could be detected in the Bangemall mineral. The formula calculated from the analytical figures is :

$$H_8Mg(Al,Fe)_4Si_6O_{23}.4H_2O+0.14(Na,K)_2O.$$

This is not very far from that calculated for type beidellite, viz. :

$$H_8(Ca,Mg)_{\frac{1}{2}}(Al,Fe)_4Si_6O_{22\frac{1}{2}}.4H_2O.$$

In the higher proportion of monoxides (MgO+CaO) it resembles montmorillonite, of which beidellite is possibly only a ferriferous variety, with some Fe_2^{III} replacing MgSi.

This is the first record of beidellite for Australia.

The Bangemall beidellite is evidently an epigene mineral of the clay group. There are a large number of these clay minerals whose constitution has not been finally settled, owing to the intimate intermingling in most cases of more than one compound, partly as a mechanical mixture, partly as a true cocrystallisation of isomorphous molecules, partly as an adsorption complex. Some authorities look upon some of them as quite variable mixtures of gels precipitated from complex colloidal suspensions, rather than as definite chemical compounds.

References : 1925. Larsen and Wherry, *J. Wash. Ac. Sci.* 15, p. 465–6 ;
Ross and Shannon, *Id.*, p. 467–8.

(4) BEUDANTITE-PLUMBOJAROSITE, Mt. McGRATH†, N.W.

The Belvedere gold and lead mine was discovered in 1936. It lies 8 miles N.N.E. of Mt. McGrath in country composed of metasediments of the Ashburton Series (Precambrian), with which are interbedded basic tuffs and lava flows. Two samples of oxidised ore, with a gangue of quartz and kaolinised schist, were found to have the following metallic contents :—

	Lead. Per cent.	Copper. Per cent.	Silver. Oz. p.t.	Gold. Dwt. p.t.
A	9·70	0·18	7·09	13·80
B	11·21	0·84	2·66	6·54

†Lat. 22° 40′ S., Long. 116° 14′ E.

As arsenate and acid soluble sulphate were detected in them, a close examination of the ore was made to determine the forms in which they occurred.

The lode itself consists of a greenstone schist with a network of small quartz veins carrying at depth bunches of galena. Near the surface many of these bunches, reaching several inches in diameter, have been replaced by firm but porous ochre yellow (R 17′) to clay coloured (R 17′′) masses of what is probably a microscopic intergrowth of beudantite and plumbojarosite, with possibly a little jarosite.

Analyses were made of two slightly different looking specimens, the results being :

Beudantite—Plumbojarosite Mixture, Mt. McGrath.

—	Specimen A.		Artificial Mixture.	Specimen B
	Per cent.	Mols.	Per cent.	Per cent.
PbO	24·80	111	25·34	24·25
K_2O	·50	5	·42	n.d.
Na_2O	·34	6	·29	n.d.
Fe_2O_3	39·57	247	36·54	32·03
Al_2O_3	·44	4	...	
SO_3	14·82	186	17·00	12·37
As_2O_5	10·34	45	10·66	present
P_2O_5	trace	...	...	...
H_2O (by diff.) ...	7·76	431	8·25	present
Cl	nil	...	...	...
SiO_2	1·43	...	1·50	11·60
	100·00	...	100·00	...

Analyst : C. R. Le Mesurier.

Specimen A was typical material, porous, ochre yellow, microgranular, and firmly coherent, with an earthy lustre. Its composition approximates to that of a mixture of beudantite, 66·0 per cent ; plumbojarosite, 23·5 ; jarosite (K_1Na_1), 4·5 per cent ; and quartz, 1·5 per cent. The exact composition of such a mixture is given in col. (3) above.

Fig. 1.

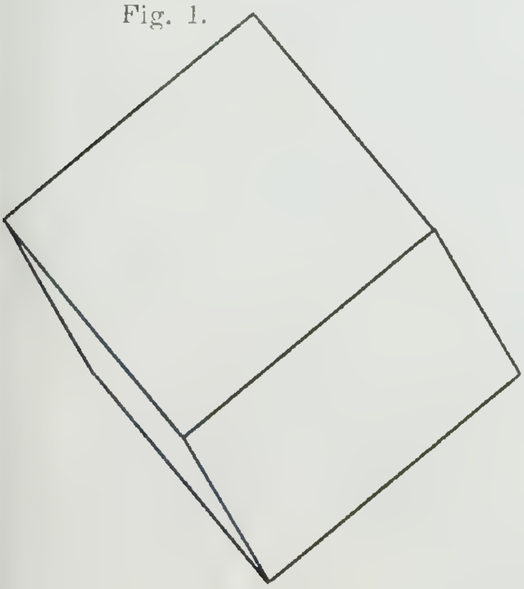

Fig. 2.

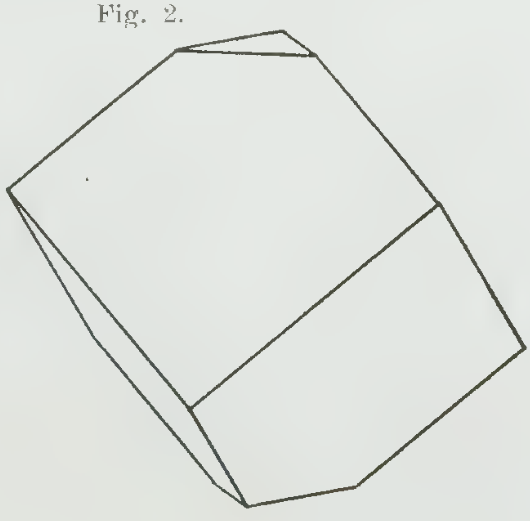

Fig. 3.

Beudantite-Plumbojarosite Crystals Mt. McGrath.

The analysed powder of "A," when viewed under the microscope, was seen to be completely and perfectly crystallised in either (1) simple rhombohedra, (2) rhombohedra slightly truncated by basal planes, (3) flat hexagonal discs, with basal planes connected by rhombohedral faces (figs. 1, 2, 3), and rarely (4) the same connected by hexagonal prism faces. The crystals are all very minute running from 2 to 20 microns in diameter, the average being well under 10 microns. They are transparent and uniform in colour, pale amber to deep amber according to thickness.

As the three species thought to be present are similar in crystallisation and colour, and all have refractive indices higher than methylene iodide, it is not possible to separate them under the microscope. It is probable indeed that the jarosite-natrojarosite molecules are not present as a separate mineral, but are cocrystallised with the beudantite, with which theoretically they should be completely isomorphous, the composition of the minerals being :

Beudantite	$PbFe_3'''(OH)_6(SO_4)(AsO_4)$
Jarosite	$KFe_3'''(OH)_6(SO_4)_2$
Plumbojarosite	$PbFe_6'''(OH)_{12}(SO_4)_4$

This appears to be the first occasion on which either beudantite or plumbojarosite has been found in Australia.

(5) CALCIOSAMARSKITE, HILLSIDE*, N.W.

In 1928 H. V. Ellsworth described a mineral from Hybla, Ontario, which differed from samarskite by the displacement of most of the ferrous iron by lime. For this new species he suggested the name calciosamarskite. Both this and samarskite appear to belong to the euxenite group, of which the chief members are :

Yttrotantalite	$Y_2Ta_2O_8$
Polycrase	YTi_2NbO_8
Tantalopolycrase†	YTi_2TaO_8
Euxenite	$YTi_2NbO_8+Y_2Nb_2O_8(+CaTiNb_2O_8$, etc.)
Tanteuxenite	$YTi_2TaO_8+Y_2Ta_2O_8(+CaTiTa_2O_8$, etc.)
Samarskite	$Y_2Nb_2O_8+Fe''U^4Nb_2O_8$
Calciosamarskite	$Y_2Nb_2O_8+CaU^4Nb_2O_8$

In each of these minerals there are a large number of isomorphous displacements, *e.g.*, Ta-Nb, Y-Er, etc., Ti-U-Zr, Fe''-Mn''-Ca. Autoxidation converts much, if not all, of the U^4 into U^6 in early Precambrian minerals of the group. Up to the present calciosamarskite has only been recorded from two localities, viz., Hybla and Parry Sound, both in Ontario.

The rapid rise in the price of tantalum ores in 1936–7 stimulated prospecting for such minerals in Pilbara, and as a result calciosamarskite was found four miles N.W. of the homestead on Hillside Station. It formed the greater part of a pebbly alluvial concentrate, its associates being microlite, an undetermined phosphate, iron ores, quartz, and microcline. It was doubtless originally formed in one of the numerous tantalum-bearing pegmatites which occur throughout this region.

*Lat. 21° 45′ S., Long. 119° 25′ E.

†Known in Western Australia but previously included under Euxenite or Tanteuxenite.

In composition, and physical and chemical properties, it closely approximates Ellsworth's descriptions of the Canadian minerals. An imperfect analysis showed :

Nb_2O_5, Ta_2O_5	Y_2O_3	CaO	FeO	MnO	PbO	UO_3	TiO_2
58·3	16·5‡	6·0	3·5	1·0	2·0	8·0§	1·0

SnO_2	H_2O	Total	G
2·6	2·0	100·9	5·60

‡Includes a little Ce_2O_3. §Includes traces of BeO and UO_2.

The pebbles range in weight up to 10 grammes. The surface has a thin coating of light grey to brownish alteration products, but on a fresh fracture the mineral is brownish black with a resinous lustre. It has a hardness of $5\frac{1}{2}$. The specific gravity was determined on 20 more or less thinly coated pebbles. It ranged from 5·73 to 5·03, with an average of 5·60. The two lightest pebbles with G, 5·25 and 5·03 were probably more weathered or more hydrated than the others. The carefully cleaned piece used for analysis had the average specific gravity.

Under the microscope the powder has a maximum translucency of about 0·3 mm. The colour of the more transparent granules is olive brown, and they are, like so many hydrated rare earth minerals, abnormally isotropic. In a closed tube the mineral decrepitates energetically when heated, and yields a little water without melting.

The spot where this mineral was found is only seven miles from Eleys where monazite, tanteuxenite and tantalopolycrase occur ; and twelve miles from Cooglegong where monazite, gadolinite, hydrogadolinite, metagadolinite, hydroallanite, tanteuxenite and yttrotantalite have been found.

Reference : 1928. Ellsworth. *Amer. Min.* 13, p. 63–8.

(6) CHRYSOTILE—ANTIGORITE, MEILGA*, N.W.

The very highly priced chrysotile, exported to England from the Silversheen Asbestos Mine on Meilga Station in the valley of the Henry River, occurs under unique conditions. Practically every other known occurrence of commercial chrysotile is in an intrusive mass of serpentine, representing a metamorphosed peridotite or hypersthenite. The Meilga mineral occurs in a Precambrian sedimentary dolomite along the walls of one or more intrusive dykes of typical fresh augite-labradorite dolerite without olivine. The marmorised grey dolomite close to one of the dykes, has been converted by hydrothermal action over a width of about 15 feet, into an almost pure massive antigorite, slightly contaminated on the actual contact with calcite and one or two as yet undetermined minerals. The chrysotile occurs in almost horizontal groups of veins forming networks in this antigorite, the veins yielding cross fibre from a few millimetres to 10 centimetres (one sixteenth to 4 inches) in length. The two widest veins measured were 10 and 12 cm. in width, with the usual planes of parting at 4 and 3 cm. from one wall respectively, but veins are said to have been seen in the mine up to 15. cm (6 inches) in width.

*Lat. 23° 0′ S., Long. 115° 50′ E.

Analyses of the massive antigorite and fibrous chrysotile are given below :

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO
(1) Chrysotile best ...	41·93	·23	tr.	·43	·05	41·99	·03
(2) Chrysotile 2nd grade	40·71	·08	·86	nil	tr.	31·85	8·21
(3) Antigorite	41·95	·29	tr.	·34	·06	42·76	nil

	H_2O+	H_2O-	CO_2	Alks.	Total.	G.	Analyst.
(1) Chrysotile best ...	13·47	1·17	1·34*	nil	100·64	2·37	Rowledge.
(2) Chrysotile 2nd grade	8·78	1·62	7·71†	nil	99·82	2·52	Rowledge.
(3) Antigorite	13·81	·87	nil	nil	100·16‡	2·48	Grace.

		*	†
*† Equal to $CaCO_3$	... ...	·05	14·65
$MgCO_3$	... ...	2·53	2·43

‡ Includes TiO_2	... ...	·01
P_2O_5	... ...	·07

The antigorite which forms the matrix of all the chrysotile veins is homogeneous, massive and translucent, often highly so, resembling wax or hard soap. Its colour is mostly pale cream, but some is almost white, whilst other specimens are of various shades of light amber and pink, to a dirty yellowish grey in rare instances. Even the latter shows diffuse daylight through a thickness of one centimetre, but some of the whitest antigorite is less translucent, probably owing to the presence of diffused microscopic granules of calcite.

The chrysotile too, though quite white in all cases when teased out, ranges in colour when in mass from pure white, through pale yellow and pink, to deep amber and reddish amber, most of the colours being elusive owing to the high translucency and chatoyance of the specimens, no Ridgway standard coming near them as a rule. Rarely some of the fibre embedded in the darkest coloured antigorite approaches a bronzy brown in certain lights. There is no tinge of green in any of the chrysotile. Very beautiful specimens are found of cream coloured waxy antigorite traversed by small anastomosing veins of salmon pink chrysotile with end faces of " apricot buff " to " apricot orange " (R. 11′b –11′) where the butt end of the asbestos has broken cleanly away from the antigorite matrix. Other notable specimens have a matrix of translucent antigorite shading from faintly greenish yellow to dark brownish grey, traversed by veinlets of soft translucent chrysotile with a chatoyance changing from bronze brown to golden yellow. The translucency for diffuse daylight of this dark chrysotile is at least one centimetre in the direction of the fibre, but only half that across it. That of the bright reddish amber is over five centimetres along the fibre and 1·5 to 2·0 across it.

There is no constant relationship between the colour of the veins in mass and their commercial value, which depends on the fineness, flexibility and tensile strength of the separated fibres. Some of the best mineral, sold at £150 a ton, has been pure white, but almost equally valuable fibre has been coloured various tints of amber to reddish orange. The darkest fibre has usually been brittle and comparatively harsh, but so has some of the palest coloured. The analyses show that even the purest and most translucent specimens have extremely thin invisible films of calcite, dolomite, and magnesite along the fibres. Where these do not form more than 2 or 3 per cent of the whole, they have not been found to reduce the market value.

(7) CORDIERITE—ANTHOPHYLLITE, CLACKLINE*, S.W.

In 1937 Mr. F. G. Forman, Government Geologist, found a very unusual looking crystalline rock about one mile N.W. of the railway station. This I have since examined both in the field and in the laboratory. It forms a small lens, possibly a laccolite, flanked on either side by Precambrian sillimanite-quartz-biotite schists which are almost vertically bedded. The outcrop measures only about 100 x 20 feet, and there is no other similar outcrop anywhere near it. A few hundred yards to the north, and about the same distance to the south, gneissic granite cuts across the bedding of the metasediments.

The laccolite is composed of a rather coarse grained grey and slightly gneissic rock composed of equal parts of brownish white anthophyllite and grey to dull blue cordierite. The balance of the rock, about five per cent. of the whole, consists of chlorite, sericite, rutile and chromite. The only similar rock of which any account can be found is one in Finland, described by P. Eskola in 1914, and thought to be a " pneumatolytic metamorphic rock "

The " anthophyllite-cordierite granulites " in Cornwall described recently by C. E. Tilley, and the quartz-cordierite-anthophyllite rock in Sweden described by W. Larsson, appear to be different in nature and origin to the Clackline rock. They are much more siliceous (SiO_2 65·7 and 67·5 per cent.), and contain quartz and sodic plagioclase as important constituents.

The chemical composition of the Clackline rock is as follows :—

Cordierite—Anthophyllite Rock, Clackline.

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O
52·66	13·99	2·15	7·08	·12	20·20	·25	·08

K_2O	H_2O+	H_2O-	TiO_2	CO_2	P_2O_5	FeS_2	Cr_2O_3	Total	G
·06	3·33	·13	·36	·02	·05	nil	·19	100·67	2·89

Analyst : H. P. Rowledge.

The calculated norm is :

Qtz	Cor	Or	Ab	An	Hyp	Mgt	Crm
16·63	13·47	·33	·68	·89	60·97	3·13	·27

Ilm	Ap	H_2O+CO_2	Total
·68	·13	3·48	100·66

Both chemical composition and norm are unique for a West Australian rock.

The cordierite for the most part forms anhedral grains from 1 to 3 mm. in length. At rare intervals dull blue or violet masses of pure cordierite up to nearly 10 mm. in diameter are visible in hand specimens. In a thin slice under the microscope the mineral appears colourless and transparent, is devoid of crystal boundaries or cleavages, and encloses a small amount of minute dusty granules, and an occasional small crystal of anthophyllite or rutile. Veinlets of scaly chlorite and sericite traverse the mineral in an irregular network, but form only a very small proportion of the whole, which is unusually fresh and free from deep seated or surface alteration.

The associated anthophyllite is idiomorphic, forming prisms from 0·05 to 5 mm. in length, pale brownish amber in mass, but colourless under the microscope. The crystals show the characteristic high birefringence, straight extinction and positive elongation.

*Lat. 31° 45′ S., Long. 116° 32′ E.

The origin of the rock is obscure, but I am inclined to consider it as a laccolite closely related to the numerous hypersthenite dykes which occur within a 25-mile radius, the magma having been altered by absorption of some slate or similar aluminous rock.* The high percentage of magnesia, and presence of appreciable chromium is significant in this respect, as is also the low proportion of lime and alkalis.

References : 1914. Eskola, *Bull. Comm. Geol. Finlande,* 40, p. 169, 187, 252.
(Abs. 1928. A. Holmes, Nomenclature of Petrology, p. 69.)
1932. Larsson, *Bull. Geol. Inst. Upsala,* 24, p. 118.
1937. Tilley, *Geol. Mag.* 74, p. 300–9.

(8) FAYALITE—HEDENBERGITE, BURGES FIND†, S.W.

A unique type of gabbro has been found at Burges Gold Find, ten miles south of Burracoppin. It forms a dyke associated with Precambrian amphibolite and metasediments in an area almost surrounded by granite.

The rock is a very fresh, coarse grained mixture of labradorite, hedenbergite, hornblende, fayalite, apatite, magnetite, ilmenite, and pyrite. Its composition is :

Fayalite-gabbro, Burges Find.

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O+
40·18	7·90	6·34	27·38	·70	·70	10·91	1·20	·24	·10

H_2O-	TiO_2	CO_2	P_2O_5	FeS_2	Cr_2O_3	V_2O_3	Total	G
·17	2·51	·11	·68	·66	nil	·05	99·83	3·47

Analyst : J. N. A. Grace.

The extraordinarily high molecular ratio of FeO to MgO (23 to 1) indicates that the chief ferromagnesian minerals are the unusual species, fayalite (Fe_2SiO_4) and hedenbergite ($CaFeSi_2O_6$).

Microscopic investigation confirms this. In section the fayalite is in large rounded transparent grains, traversed by many cracks, and showing a high birefringence and slight pleochroism, light yellow (β) to very pale greenish yellow (α, γ).

The hedenbergite is in more angular, but rarely idiomorphic grains, showing the prismatic cleavage plainly. The mineral is much less transparent than the fayalite, and is weakly pleochroic ; α, medium bottle green ; β, yellowish green ; γ, deep bottle green. The maximum extinction angle measured was 48°.

This is the first record of these two minerals for Western Australia.

References : 1936. *W.A. Chem. Branch An. Rept.* 1935, p. 6.
1936. *W.A. Geol. Surv. An. Rept.* 1935, p. 34.

(9) PETALITE, LONDONDERRY‡, Cen.

In 1933 the writer inspected Seahill's Felspar Quarry on M.L. 72 (now 80) at Londonderry, and found a few small cores of slightly altered petalite embedded in large masses of a quartz-chalcedony pseudomorph. This occurrence was described in Series VIII. of these Contributions.

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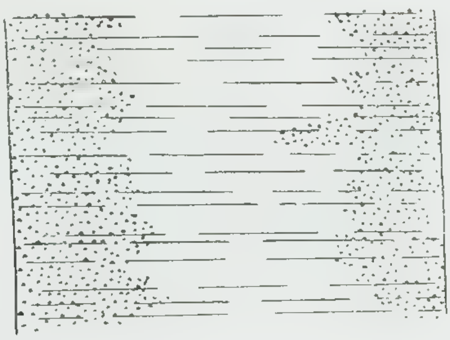
*Thus : $\underset{\text{Enstatite}}{9MgSiO_3} + \underset{\text{Kaolin}}{2H_4Al_2Si_2O_9} \longrightarrow \underset{\text{Cordierite}}{Mg_2Al_4Si_5O_{18}} + \underset{\text{Anthophyllite}}{H_2Mg_7Si_8O_{24}} + \underset{\text{Water.}}{3H_2O}$

†Lat. 31° 35′ S., Long. 118° 30′ E. ‡Lat. 31° 5′ S., Long. 121° 7′ E.

In October, 1937, a further inspection of the quarry was made. The felspar (microcline) vein was then being exploited energetically by Australian Glass Manufacturers, Ltd., and the quarry had reached a depth of 45 feet with a width and length of over 100 feet.

It was immediately apparent that much of what the quarrymen had been taking for quartz, and throwing away on the waste dump, was in reality petalite. Many tons of it were to be seen in the north face of the quarry and in the dump, where also were large quantities of various pseudomorphs after it, apparently originating in the latest stages of vein development.

About one-quarter of the whole rock broken in the quarry is clean white microcline, which is shipped to factories in the Eastern States. Other common constituents are quartz, albite, petalite, pseudomorphs after petalite, lepidolite, beryl and spessartite. An occasional crystal of manganocolumbite has been found. The petalite occurs mostly if not wholly in veins or in lenses, one inch to two feet (2 to 60 cm.) in width in the pegmatite. These veins, in almost every case, are completely filled with uncontaminated petalite or pseudomorphs after it. The exceptions are where a later quite small fissure in the petalite is filled with albite and lepidolite. The same two minerals frequently form the walls of petalite veins.



Petalite vein, Londonderry, converted along the walls into an Albite-Chalcedony Pseudomorph.

Fig. 4.

The vein fillings consist either of pure unaltered petalite, of petalite partly replaced by pseudomorphs against one or both walls (Fig. 4), of small of petalite with ragged boundaries completely surrounded by a pseudo-

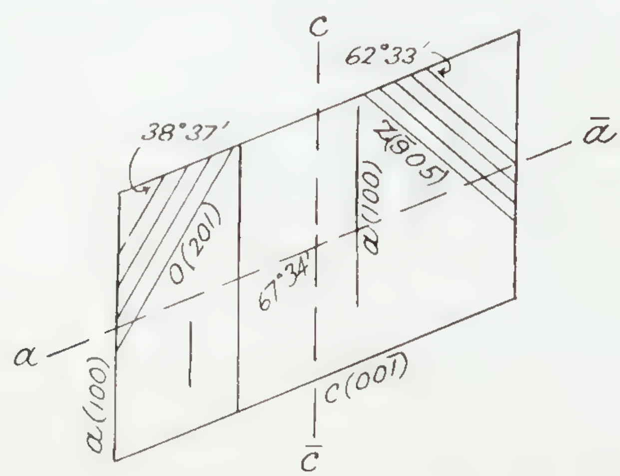
ERRATUM.

Page 116, second line from bottom, for "quartz-chalcedony pseudomorph," read albite-chalcedony pseudomorph.

The purest mineral is water white and perfectly transparent up to 1 cm. or more. It has a hardness of $6\frac{1}{4}$, specific gravity 2·41 and the composition shown in Col. 1. The majority of specimens however show white streaks

or clouds of less translucent mineral, probably due mainly to the presence of minute fluid inclusions. Frequent air filled cleavages also help to interrupt the light. The composition of some of the slightly cloudy mineral is given in Col. 2. This original analysis was made in 1933 on a very small core of cloudy petalite completely embedded in albite-chalcedony pseudomorph, and may have been slightly contaminated with decomposition products.

The cohesion of the pure mineral is of interest. The masses of it are considerably fissured by cleavages and partings. Always prominent is the basal cleavage, described in the text books as "perfect" or "vollkommen." It is not, however, perfect in the sense that the cleavage of mica, gypsum, or galena is so described, as although it is very prominent, and of broad uninterrupted extent, the mineral shows no inclination to part in repeated thin layers even under considerable side pressure or impact. On the contrary it is more like a parting than a cleavage, as it is unevenly spaced, and when broken at right angles to it, the mineral yields large uninterrupted conchoidal or subconchoidal surfaces 1 to 10 mm. wide between the cleavage traces. This cleavage is always at right angles to the walls of the veinlets, and probably owing to pressure from them, in some specimens shows a few slight changes of direction amounting to one or two degrees, resembling those produced by multiple twinning in such minerals as plagioclase or amblygonite. The finest specimens give such a brilliant reflection from the broad basal cleavages as to resemble colourless topaz, and it has been suggested to me that such specimens might be cut into gems. A 2½ carat brilliant cut from such material was perfectly transparent and flawless, and of considerable brilliancy. It lacked fire however, owing to the low dispersion of petalite, viz. b–r = 0·010. In these specimens there is often no indication of any other parting or cleavage. Usually, however, the traces of innumerable cross fractures are visible, giving a rougher and duller appearance to the basal plane.



Petalite, Londonderry. Projection on b(010), showing minor cleavages, the prominent basal cleavage omitted.

Fig. 5.

Quite strongly developed in some specimens is a series of partings at right angles to $c(001)$ and parallel to $b(010)$. Other less frequent and distinct partings are $a(100)$, $o(210)$, and $z(\bar{9}05)$, making angles with c of + 67½°, + 38½°, and — 62½°. (See Fig. 5.) In consequence of the multiplicity of

such partings certain specimens have a cross hatched appearance on their surfaces. The infiltration of minute amounts of brown kaolin and limonite from the soil along the cleavages gives some specimens an amber tinge.

The Londonderry petalite before the blowpipe fuses on thin edges, and colours the flame red. In a closed tube it gives a red glow below normal red heat.

After the original deposition of the petalite, renewed fracturing of the pegmatite vein took place and strong sodium-bearing solutions penetrated them, upsetting the established equilibrium, and producing pseudomorphs after petalite, in accordance with the following equation :

$$LiAlSi_4O_{10} + NaX \longrightarrow (NaAlSi_3O_8 + SiO_2) + LiX \text{ (removed in solution).}$$

Weight change + 5·2 per cent.

Volume change — 3·4 per cent.

Subsequently the intimate microscopic intergrowth of albite and chalcedony this produced was further altered by hydrolysis, and addition of small quantities of potash, lime, magnesia, iron and manganese, with the formation of indeterminate mineral mixtures, including probably montmorillonite.

Three main types of pseudomorph are visible on the dump :

(A.) Hard (6½) white horny or porcellanous masses, showing remnants of the original basal cleavage.

(B.) Much softer grey pseudomorphs, hardness 3 to 5.

(C.) Lilac coloured pseudomorphs with a similar range of hardness, viz., 3 to 5.

(A.) This has previously been described in some detail (loc. cit.). An analysis of a typical specimen is given in Col. 3 of the accompanying table. It is a microcrystalline intergrowth of about 72 per cent. albite, 20 per cent. quartz, and 8 per cent. montmorillonite and sericite (?). Some very large homogeneous masses of this white opaque pseudomorph have been quarried. Other masses contain more or less small cores of petalite with hazy boundaries, and the basal cleavage continuing as a parting from the original mineral into the pseudomorph. Many instances were observed of one or both sides of a vein being converted into this pseudomorph, whilst the balance remained perfectly fresh, the surface of contact being very jagged. (Fig. 4.) In one specimen there are two veins separated by only 2 to 3 cm. of granular albite with some lepidolite. One vein, from 30 to 60 cm. wide, is completely altered into the albite-chalcedony pseudomorph, the other is perfectly unaltered, except for a very thin layer of albitised mineral on the inner wall.

(B.) The grey pseudomorph varies in colour from pale neutral grey to deep greenish grey (about R 35[5]). Occasionally there is a slight buff or purplish tinge in the grey. Rarely is the colour uniform, usually there are included in it rounded or streaky areas of white with indistinct boundaries. The hardness is lower than that of petalite or the white pseudomorph, hovering round 4½. Some specimens have a slightly silky lustre, but mostly it is dull. The original basal cleavage of the petalite is represented by a strongly marked parting at wide intervals, or by a general foliated structure parallel to it. Rarely this pseudomorph surrounds a small remnant of petalite. It is quite complex in composition as the analysis in Col. 4 shows, and it is to be noted that there is a little lithia left in it. It is usually found not far from a concentration of lepidolite with spessartite and albite, and evidently indicates some unusual and purely local conditions during alteration.

(C.) The lilac coloured pseudomorph, like the grey, is seldom homogeneous as regards colour or hardness. The latter ranges round 4. The commonest colour is between "mauvette" (R 65'f) and "lilac" (R 65'd). Some of it is paler and more pinkish. This pseudomorph is found both as ragged inclusions in the white pseudomorph (A.), as mottled mixtures with it, and finally as large almost homogeneous, masses. The original basal

Petalite, Londonderry.

No.	1	2	3	4	5	6
	Petalite, colourless transparent.	Petalite, colourless milky.	Milk white hard pseudomorph.‡	Olive grey pseudomorph.	Lilac pseudomorph.	Lilac pseudomorph.
SiO_2	78·68	76·19	74·48	78·26	77·83	72·60
Al_2O_3	16·62	16·48	15·52	13·34	14·93	16·64
Fe_2O_3	·09	·21	·17	·93	·14	traces
FeO	nil	nil	nil	·46	nil	nil
Mn_2O_3	·004	trace	nil	·31	·20	0·67
MgO	nil	·54	·11	·28	·31	·37
CaO	nil	nil	·20	·26	·54	1·32
BeO	spec. tr.*	?	?	spec. tr.†	?	present
Li_2O	4·13	3·72	nil	·64	1·11	·94
Na_2O	·08	·36	7·72	·36	·10	·68
K_2O	nil	·18	1·22	·18	nil	·25
H_2O+	·01	1·04	·40	4·49	4·48	5·76
H_2O-	nil	1·22	·50	·84	·55	n.d.
Total	99·834	99·94	100·32	100·35	100·19	99·23
G	2·41	2·38	2·61	2·615	2·60	...
H	6	6	7	4–5	3–5	...
N	...	1·514, ·510; ·502	...	...	...	...
Analyst	H. P. Rowledge	C. R. Le Mesurier	C. R. Le Mesurier	D. G. Murray	C. R. Le Mesurier	H. Bittner

* BeO, less than 0·02 per cent. † BeO, less than 0·004 per cent. ‡ Another specimen had SiO_2, 72·35. G; 2·64.

cleavage of the petalite is easily distinguished in the harder specimens as a more or less widely spaced parting, but is not so conspicuous in the softer and presumably more altered ones. The composition is again very complex, as shown by the two analyses in Cols. 5, 6. The lithia found is undoubtedly present in remnants of original petalite, of which innumerable small specks in optical continuity are embedded in the decomposition mixture. The lime and magnesia are probably present as montmorillonite, whilst the Mn_2O_3, which is derived from adjacent lepidolite and spessartite, or the solutions which generated them, replaces part of the alumina of the montmorillonite to which it imparts the lilac colour.

This occurrence on M.L. 80 at Londonderry is undoubtedly one of the most remarkable deposits of petalite in the world.

Two miles north of it, in the same belt of Precambrian amphibolite, are some small tin and tantalum workings at what was once known as Mercer's Find. In 1937 a pegmatite vein on abandoned M.L.61 was opened up to a depth of about 10 feet in search of manganotantalite. The vein consists mainly of quartz, albite, microcline and a very dark botryoidal lepidolite or zinnwaldite. On the dump the writer observed a few fragments of a pseudomorph after petalite, which were traced to one or two small secondary veins in the pegmatite. These veins were only 3 to 6 cm. wide and were wholly filled with the pseudomorphs. No unaltered petalite was seen, but the alteration products are identical with some of those in the quarry on M.L. 80. The colour varies from white to lilac on the one hand, and through pale neutral grey to greenish grey or olive grey on the other. Both types have the same specific gravity, 2·53, with a hardness ranging from $4\frac{1}{2}$ to $5\frac{1}{2}$. The white material forms cloudy patches in the coloured. It is not as hard and dense as the porcellanous white material in M.L. 80. A strong parting is continuous across the veins, being undoubtedly the relic of the basal cleavage of the original petalite, which further mining operations may expose.

Reference: 1933. Simpson, *Jour. Roy. Soc. W.A.*, Vol. 20, p. 58–9.

(10) SPODUMENE, McPHEES RANGE*, N.W.

The opening up of a new tantalum vein near Pilgangoora Trig. Station (CC 32) has revealed the presence of a considerable amount of spodumene. The vein is a pegmatite (in Precambrian greenstone) of which quartz and albite are the principal constituents. Cassiterite, manganocolumbite and manganotantalite are irregularly distributed through it, as also are spodumene, beryl, garnet, biotite, lepidolite and muscovite. It was observed by H. Bowley in samples submitted for assay that wherever spodumene was present, the tantalum minerals were abundant, and cassiterite comparatively rare. In some specimens the small crystals of tantalum mineral are completely embedded in spodumene.

The spodumene is said to be found at times in very large masses in the veins. In specimens brought to Perth it is visible in imperfect crystals, up to 10 x 5 cm., with strong prismatic cleavage. The forms developed are usually *a* and *m*. No terminal faces were recognised. The colour ranges from milk white to pale neutral grey, or pale purplish grey (R 67^5d). The translucency for diffuse daylight reaches 4 mm. in some specimens, but is usually a little less. The maximum refractive index is about 1·68, extinction angle 28°, and elongation positive. The specific gravity is 3·10 to 3·14.

* Lat. 21° 5′ S., Long. 118° 55′ E.

The composition of a typical piece was found to be normal, the figures being :

SiO_2	Al_2O_3	Fe_2O_3	Mn_2O_3	CaO	MgO	Li_2O	Na_2O
63·83	27·34	·15	·08	·22	nil	7·08	·44

K_2O	TiO_2	CO_2	P_2O_5	H_2O+	H_2O-	Total	Analyst—
·22	nil	·10	·06.	·18	·06	99·76	C. R. Le Mesurier

In one part of the vein some interesting pseudomorphs have been collected. These consist of dense masses of microscaly muscovite, preserving the external faces of the original spodumene and at times, like the unaltered spodumene, enclosing pieces of tantalum ore. They range in colour from light vinaceous grey (R. 69^4d) to near vinaceous purple (R. 65^3), the colour being doubtless due to Mn_2O_3. A determination of the alkalis showed :

	Li_2O	Na_2O	K_2O	Sp. Gr.
Per cent	0·10	·22	8·12	2·81

This is another instance of the latest stages of pegmatite formation being characterised by the invasion of highly active potassic solutions. In veins at Melville and Londonderry under such conditions large masses of topaz have been altered to a considerable depth into cryptocrystalline muscovite, whilst at Melville and Westonia large masses of cordierite have been almost entirely altered into muscovite.

Acknowledgments.—I desire to acknowledge my indebtedness to the Government Geologist, Mr. F. G. Forman, for three of the specimens herein described, and to Messrs. J. N. A. Grace, C. R. Le Mesurier and H. P. Rowledge of the Government Laboratory for making several analyses for me.

A REGIONAL CLASSIFICATION OF THE SOILS OF WESTERN AUSTRALIA.*

PRESIDENTIAL ADDRESS

By L. J. H. TEAKLE.

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I.—INTRODUCTION.

The recording of scientific information concerning Western Australia is of fundamental importance for the understanding of the conditions existent in the State and for the promotion of sound development. From the point of view of the physical sciences the most important attempts which have been made include the geological maps of the State prepared by Gibb-Maitland and Blatchford of the Western Australian Geological Survey, and by David (1932), the work on minerals by Simpson, Jutson's (1934) "Physiography," Clarke's (1926) regional classification, the vegetation map of Kessell and Gardner (see Kessell, 1928) and of McTaggart (1936), and the soil map of Prescott (1931, 1933). In his account of the physiography of Western Australia Jutson has recognised and described 9 physiographic Divisions, and Clarke has subdivided the State into 15 so-called natural regions.

Each of these workers has succeeded in recording in a systematic manner observations concerning the conditions in the State, but, except for the publications by Prescott (1931, 1933), no attention has been paid to soil conditions and soil problems.

When it is appreciated that the soil type, broadly speaking, represents the integration of the most important ecological factors of biology (including both plant and animal organisms), climate, geology and relief, it is apparent that the soil is probably the best and certainly the most inclusive basis for a regional survey of any geographic unit. Consequently no apology is needed for this extension and elaboration of the work of earlier contributors.

In viewing the situation in Western Australia the soil scientist, or pedologist, is faced with the problem of mapping an area of nearly one million square miles; an area representing one of the oldest land surfaces of the globe and in which the occurrence of fossil soil horizons has multiplied the complexity normally due to the interaction of geological, climatic and biological factors.

The first map of the soils of Western Australia was prepared by Prescott (1931, 1933). Prescott provided an elucidation of the enigma when he recognised the extensive ferruginous and aluminous gravel formations, or laterite, to be the remains of an ancient B horizon of a soil—to be a fossil subsoil. These gravels occur in all parts of the State older than late

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Cainozoic, and are associated with azonal* soils of low fertility. With the recognition of the importance of these azonal soils the picture became more clear and it was possible to recognise soil zones corresponding to some of the *great soil groups* of the world.

Prescott recognised six major soil zones in Western Australia, and the zonal soils of Western Australia were found to resemble those of corresponding zones of the Eastern States. Furthermore, these zonal soil types actually formed on the exposures of country rock, on alluvial material, etc., while generally the azonal soils were typical of the higher levels where lateritic gravels covered the country rock. Observations left no doubt that they were related to this fossil soil horizon of the ancient plateau, *the Great Plateau of Western Australia*, which is now undergoing erosion under the present cycle.

More recent observations have confirmed Prescott's generalisations. They have also provided information for more accurate description and delineation of the soils of the zones, for the definition of a new major soil zone probably not developed extensively outside this State (Teakle, 1936), and for the subdivision of the zones into regions in which the recurrence of soil, ecological, and topographical conditions are very generally similar. It is the purpose of this paper to present the conception of soil regions in Western Australia and to describe such regions which have been mapped to afford a closer, yet still broad, definition of the soil conditions of the State.

II.—THE CONCEPTION OF A SOIL REGION.

Most schemes for soil classification are designed to define the unitary soil type or soil series in terms of pedogenic factors and stage of development just as plants or animals are classified, but, geographically speaking, subdivision of the great soil groups must be based on soil associations or complexes. Each association will embrace a considerable number of soil series and intrazonal soils, and in this paper has been termed a *soil region* on account of the broadness of the subdivision. Within each soil region the general topographic, climatic, and ecological conditions will be the same; agricultural, forestry, and pastoral possibilities and problems will be similar; and the area will be represented by a reasonably constant association of principal soil types. A similar attempt has been made in the preparation of a soil map of the Union of South Africa. The basic idea in the present classification, however, more closely resembles that underlying the "catena"† of Milne (1935) but is considerably more broad and each region may include a considerable number of catenary units.

In this subdivision the area of a soil region ranges from nearly 3,000,000 to over 140,000,000 acres. It is realised that for many practical purposes the unit is far too large and that, due to insufficiency of observations, the boundaries of the regions in many cases are imperfectly fixed; that in many cases the boundaries are too indefinite to be fixed accurately, as the regions may merge one into the other; but it is believed that the

* Azonal soils are those which occur in a number of zones of the area, but do not react to the soil-forming factors with the exhibition of the recognised characters of the soils of those zones.

† The term catena is used to denote a sequence of soil types, generally related to topography, forming a complex which constantly recurs throughout the area.

map and text represent a summary of existing knowledge of soil conditions in Western Australia. It will, therefore, provide a basis for future soil and ecological investigations in the State.

III.—PHYSIOGRAPHY AND GEOLOGY.

Although Western Australia has an area of 975,920 square miles and stretches from 35° S. lat. to 14° S. lat., it possesses little variety in its broad physical features and geologically is predominantly of Precambrian and Palaeozoic age. Physiographically, the area may be divided into two major physical zones: a vast plateau or tableland and a narrow, low-lying almost continuous littoral strip. A new plateau is being formed under the present cycle of erosion from the "Great Plateau of Western Australia," by dissection and truncation, and, generally, the most prominent physical features of the land mass are the monadnocks and other residuals of the previous period of planation. Certain residuals of a still earlier cycle of erosion do occur but are of small extent. Fault blocks and fault scarps occur in many localities, e.g., Stirling Range, the Darling Range, etc.

The surface of the Great Plateau was gently undulating and rose gradually from the coastline, like an upturned saucer, to a general height corresponding to about 2,000 feet above sea level at the present time. The average height would correspond to a present elevation of 1,000 to 1,500 feet above sea level. Mention should be made, of course, of the Hamersley tableland in the North-West, where Mount Bruce now attains a height of over 4,000 feet.

Except in the Kimberley Division in the extreme north of the State, the topography is generally mature or senile. Broad valleys, often characterised by salt channels and extensive salinas, bounded by rounded highlands or by gently undulating tablelands, the residuals of the Great Plateau, are typical topographic features of the greater portion of the State. These broad valleys form the "new plateau" now in course of construction.

The geological formations of the State are predominantly Precambrian. Granitoid formations, with associated basic igneous rocks such as greenstones and dolerites, are most important in the south, while in the north, Precambrian or Palaeozoic sediments with associated igneous rocks are practically continuous. The Warrawoona, Mosquito Creek and Nullagine series predominate north of the Tropic of Capricorn but are associated with important Permian deposits in the Kimberley and Gascoyne Districts. In the south, in addition to the main granitoid masses, recent research (Forman, 1937) has shown that Precambrian sediments, for example the Whitestone Series, are more important than originally recognised. In the coastal areas generally a greater variety of more recent sediments are encountered. Jurassic rocks occur generally from Derby to Perth, Cretaceous sediments are extensive between North West Cape and Gingin, Tertiary and recent deposits occur from Broome to Eucla.

Raggatt (1936) and Raggatt and Fletcher (1937), have given a valuable and detailed description of the Tertiary, Cretaceous and Permian formations of the North-West Basin and, in their discussion, include the coastal area between Murchison River and North-West Cape.

The Nullarbor Plains are composed of horizontally bedded, marine limestones of Miocene age, and the spicular sandstones and other deposits of this age have been recognised over considerable areas in the more southerly parts of the State.

IV.—CLIMATE.

Climatically, Western Australia may be divided into three provinces.

A.—The Tropical areas of summer rainfall in the north: rainfall 10 to 50 inches per annum.

B.—The temperate areas of winter rainfall in the south: rainfall 10 to 60 inches per annum.

C.—The central province of low rainfall, generally under 10 inches per annum, which serves as a buffer between provinces A and B.

Approximately half of the State falls in province C—has an average annual rainfall of less than 10 inches per annum.

Province A.

The rain generally falls in the November-April season and the mean annual temperature ranges from 75° F. to somewhat over 80° F. The Meyer ratio* ranges from 15 in the south to 100 in the extreme north. Prescott (1937) has shown that the period of moisture conditions suitable for agriculture without irrigation in the more favoured northern areas is limited to four months of the year, December to March, and, unfortunately, that the rainfall during these months is fairly unreliable when compared with places of similar climate such as Nigeria. Barkley (1931) has shown that the "Coefficient of variation"† ranges from 20 to 30 per cent. in the Kimberleys and reaches 60 per cent. in the Onslow area. Davidson (1934) reports that, on the average, precipitation in the Kimberleys exceeds evaporation only in two months, January and February, and over the great bulk of the province the monthly evaporation is always in excess of precipitation.

Rainfall per wet day is above 40 points,‡ a fact of considerable importance in soil formation, which is largely a function of the leaching properties of the precipitation.

Province B.

The south-western portion of the State, receiving an average of over 10 inches of rainfall per annum, is in the winter rainfall zone and enjoys a mild, temperate climate. From 60 to 90 per cent. of the rainfall is recorded in the April-September or "winter" portion of the year and in the drier parts of the province the "wet" season is practically confined to two months, June and July. Over the agricultural areas monthly precipitation exceeds evaporation for at least two months. The spread is June and July in the outer wheat belt and widens to the April-October period in the Frankland region, which includes the karri (*Eucalyptus diversicolor*) belt of the extreme south-west. East of Southern Cross, on the average, the monthly precipitation never exceeds the evaporation. Some discussion of these conditions has been given by Shelton (1933).

The mean annual temperature ranges from 60° F. to 70° F. Summer temperatures may be uncomfortably high during heat waves but are seldom excessive and, during the winter months, minimum temperatures

* The Meyer ratio is the annual precipitation in inches divided by the mean saturation deficit of the atmosphere in inches of mercury.

† The "Coefficient of variation" is the mean departure of the annual rainfall from the average annual rainfall, expressed as a percentage of the average annual rainfall.

‡ 100 points equal 1 inch.

seldom fall below 24° F. even in inland centres where continental conditions prevail. The cool, humid conditions of June and July temporarily retard the growth of crops and pastures but excellent growing conditions characterise the spring months.

The Meyer ratios range from 25 to over 250. If considered by months over the whole year a more interesting picture is obtained and shows that during the winter months highly humid conditions prevail and contrast markedly with the arid summer period. For example, the ratio of monthly precipitation to saturation deficit for Kellerberrin is of the order of magnitude of 35 during winter months of June and July, and drops to about unity during the summer period.

Perhaps one of the most important climatic features of this province is the very low precipitation per wet day. The maximum reaches 40 points in the vicinity of Busselton but the great bulk of the area receives less than 30 points per wet day; about one half of the province less than 20 points fall per wet day. This precipitation may accurately be described as light rainfall and is reflected by certain important soil conditions. The soils of the so-called "mallee" areas are but slightly leached and are typical pedocals.* Soluble salts of cyclic origin (brought in by means of the rainfall) accumulate in the subsoil, and salt lakes, or salinas, in the drier areas, and salt and brackish streams and springs in the wetter areas, are common features of agricultural significance.

Province C.

The central province is arid and in no month does the average precipitation exceed evaporation. The rainfall is low but relatively not as light as in the more southern areas, as the average precipitation per wet day ranges from 20 points in the south to 40 points in the north of the province. (The Nullarbor Plains constitute an exception.) An important fraction of the total rainfall is received in rains of over an inch which cause widespread flooding of the country. The mean annual temperature ranges from 70° F. to 75° F. and the Meyer ratio is less than 25.

The climatic conditions in this province are reviewed more fully in an earlier paper (Teakle, 1936).

It is observed that both soil and vegetation zonation of the State can be related to climatic factors—particularly the rainfall factor. The 10 inch isohyet practically marks the boundary of the eucalyptus woodland, or "mallee," zone and the acacia semi-desert scrub, or mulga zone: the 15 inch isohyet marks the boundary of the grey and brown calcareous, solonised soils of the eucalyptus woodland and red brown earths of the eucalyptus-acacia woodland zones: and the 25 inch isohyet the boundary of the wandoo (*Eucalyptus redunca* var. *elata*) and the jarrah (*Euc. marginata*) forests. Of these the 15 inch isohyet is of particular pedological interest in marking the approximate boundary between pedocals and pedalfers†—between soils with incomplete leaching and soils of complete leaching as indicated by lime accumulation in the subsoils.

V.—THE SOILS.

Before proceeding with the details of the soil classification it may be of some interest to give a picture, perhaps a rather speculative picture, of the possible soil history of Western Australia.

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* Pedocals show an accumulation of calcium carbonate in the subsoil, or B horizon.

† Pedalfers are soils in which aluminium and iron accumulate in the subsoil and calcium carbonate is more or less completely removed by leaching.

During a period probably subsequent to Mesozoic times the surface of the western portion of Australia was reduced by planation to a low-lying, slightly undulating plain practically devoid of striking physical features. Probably the Porongurups, the Stirling Range and Peak Charles of the Fitzgerald Peaks represent features which had withstood this planation. During at least portion of this geological period, the rainfall must have been generous and intermittent with definite wet and dry seasons. Drainage would be restricted by the low relief causing the soil to be waterlogged during the wet season and dry at other times. The conditions would be alternately reducing and oxidising which would cause iron compounds to dissolve as reduced compounds only to be precipitated as sesquioxide on drying. Over a considerable period this climate would be conducive to the formation of leached soils, and accumulation of sesquioxides, particularly oxide of iron, would occur in the subsoil. These sesquioxide formations are known as *laterite* in Western Australia. In the opinion of the writer, soils with similar ferruginous gravel in the subsoil are forming to-day under such conditions in New Zealand. Burvill (private communication) has observed similar soil phenomena in the south-east of South Australia.

Forman (private communication) has observed iron stained concretionary pebbles having somewhat the appearance of laterite, but much softer, in the Glen Innes pine plantation area, northern New South Wales. From observations in the railway cutting at Thulimbah railway siding, South Queensland (elevation 3,000 feet; rainfall 30 inches per annum), where a similar layer is exposed, Forman is of the opinion that these concretions are in the process of formation at the present time. The profile at Thulimbah consisted of grey sandy loam, 0 - 1 foot; yellow sandy loam, 1 - 2 feet; yellow coffee rock pebbles in great numbers, giving the appearance of a typical laterite in Western Australia, 2 - 3 feet. As at Glen Innes, these concretions were softer than the laterite of Western Australia. From the observations of Bryan and Hines (1930) it seems likely that laterite is at present forming in certain soil types in the vicinity of Brisbane, Queensland.

Following planation, uplift occurred to form the "Great Plateau of Western Australia" and a new cycle of erosion, with dissection and truncation, commenced. The "new" plateau of Western Australia is now in course of formation. In the course of the erosion, huge valleys have formed over practically the whole of the area (Gregory, 1914) and the Great Plateau is represented by flat topped mesas, by such formations as the Darling peneplain and by broken and rounded residuals which form many of the so-called "sandplains" of the southern portion of Western Australia.

This new cycle of erosion has removed the laterite or sesquioxide deposits from a considerable portion of the area, forming broad valleys and low rises on which the country rock is exposed. On the exposures of country rock, alluvium, etc., considerable areas of zonal, or normal, soils, showing incomplete leaching, podsolisation and similar zonal features, are reflections of present climatic conditions. Where the laterite persists, the nature of the parent material precludes the development of the distinct zonal features of the normal soils and, consequently, azonal soils occupy important areas throughout the State. Azonal or skeletal soils of similar characteristics also form where areas of quartzites and resistant siliceous sandstones outcrop and resist the soil forming agencies.

THE MAJOR SOIL ZONES OF WESTERN AUSTRALIA.

Only normal, or zonal, soils are considered in the designation of the major soil zones of Western Australia, which are as follows:—

A. Grey, yellow and red podsolised,* or leached, soils of the temperate sclerophyll forests.

B. Red brown earths of the eucalyptus—acacia woodlands.

C. Grey and brown calcareous, solonised† soils of the low rainfall eucalyptus woodlands—(*"mallee" soil zone of Prescott*).

D. Red and brown acidic soils of the acacia semi-desert scrub—mulga, etc.

E. Brown acidic soils of the spinifex semi-desert steppes of the north-west.

F. Pinkish brown calcareous soils of the Nullarbor Plains desert shrub steppes.

G. Pinkish brown calcareous soils of the acacia semi-desert scrub, mallee and salt bush—blue bush zone.

H. Brown soils of the tropical woodlands, savannahs and grasslands.

I. Red sands of the central desert sandhills—spinifex with desert acacias, desert gums and mallees (*Eucalyptus* spp.)

These major soil zones are subdivided into one or more soil regions, the features of which are briefly summarised in the recapitulation, pages 186-188.

It is the purpose of this paper to describe these zones and the regions within them in the light of field and laboratory information available. The distribution and location of the zones and regions are shown in the accompanying sketch map.

A.—ZONE OF GREY, YELLOW AND RED PODSOLISED, OR LEACHED, SOILS OF THE TEMPERATE SCLEROPHYLL FORESTS—12,930,000 ACRES.

Podsolised soils are essentially soils of humid conditions in cold to temperate regions, in which leaching has completely removed calcium carbonate and calcium sulphate, has induced an acidic reaction and has brought about a segregation into distinct horizons. Development generally takes place under forest (particularly coniferous) and heath and on sandy materials poor in basic constituents.

The typical podsol of Europe, America and New Zealand exhibits three essential horizons. The A, or eluvial horizon, consists of a layer of acidic peaty material underlain by a greyish bleached layer of mineral material. Below this is the B, or illuvial, horizon, characterised by accumulation of humus and sesquioxide as well as clay. The B horizon rests on the C horizon, or parent material.

* Podsols are essentially soils with a grey surface rich in organic matter resting on a bleached subsurface, or A_2 horizon. The subsoil, or B horizon, is generally yellowish due to sesquioxide accumulation. Leaching has been complete. Podsolised soils are completely leached but may not show these typical podsol features.

† Solonised soils have an accumulation of sodium and/or magnesium in the replaceable base fraction.

In Western Australia podsolised soils form under either a eucalyptus forest or a heath and the profile is generally more or less imperfect. Except where drainage is restricted and the soils belong more closely to the hydromorphous group, the peaty layer is not developed on Western Australian podsols but many soil types do exhibit other podsol characteristics. On the other hand, in many soil types of the zone other important podsol features are absent or poorly developed. These soils must be described as podsolised and the soil zone as one of "podsolised soils."

Geologically, the area may be described as a granitic mass intersected by basic dykes and segregations, capped with laterite and somewhat dissected. The coastal areas form a fringe of Tertiary and Post-Tertiary deposits and Permian deposits assume extensive proportions south of Busselton. Smaller areas of Permian rocks, important on account of coal measures, occur in the neighbourhood of Collie.

The Darling escarpment is a fault line which constitutes the most important physiographic feature and runs from north of Gingin to south of Nannup in approximately a straight line. The granitic hills of the escarpment rise abruptly from the coastal plain to a height of about 1,000 feet and form the western edge of an undulating peneplain.

The climate is mild, very wet in the winter and dry in the summer. The average annual rainfall ranges from 25 to 60 inches and along the south coast it is moist enough during the summer period to allow the growth of hardier perennial pasture species. Davidson (1934) has shown that precipitation exceeds evaporation for five to seven months of the year.

The zone carries the chief forest formations of the State and is noted for the important hardwoods, jarrah (*Eucalyptus marginata*) and karri (*Euc. diversicolor*). The associations may generally be described as sclerophyll forests of such timbers as jarrah, marri (*Euc. calophylla*), tuart (*Euc. gomphocephala*) and wandoo (*Euc. redunca* var. *elata*), with Proteaceous, Leguminous and other shrubs, and wet sclerophyll forests of karri with wattles, *Trymalium spp.*, etc. Some 3,000,000 acres of these forests are reserved as State Forests.

As mentioned above, the soils are of the podsolised type. Zonation is largely obscured by the overwhelming prevalence of laterite and lateritic gravel on which soil formation is distinctly inhibited.

Apart from the various shades of grey, the most characteristic surface soil colour of the zone is undoubtedly yellow. The most common subsoil colour is some combination of yellow and the surface soil in many instances shows the influence of the yellow colour. Certain types of sandy soils show a shallow surface of a yellowish grey colour and a bright yellow subsoil; the ferruginous gravelly types are predominantly yellowish in colour.

A similar occurrence of yellowish soils has been observed in the Silurian hills of Victoria between Melbourne and Albury, and in New South Wales yellow soils predominate between Albury and Henty on the Interstate Railway line. Bryan and Hines (1930) describe the soils forming on sandstones, shales and other acidic rocks in the vicinity of Brisbane as "yellow earths."

For these soils the designation "yellow podsolised soils" is proposed. Proper characterisation of these soils is at present impossible but the work of Hosking and Burvill (1938) suggests a narrow silica: sesquioxide ratio, and that they are low in humus and nitrogen. They are not truncated soils.

Podsolised soils with a grey brown surface may also be observed both in this zone and in the red brown earth zone. It is possible that they are related to the grey brown podsolised soils of the eastern part of the United States of America.

Acidic red earths are characteristic of basic rocks and basic segregations (Hosking and Burvill (1938)), and are very important agricultural soils in the most productive districts.

Intrazonal soils of the zone include the rendzina, represented by the Gingin clay forming on Cretaceous chalk, (Hosking and Greaves, 1936), and the solodi*, which forms on flats liable to winter flooding and salt accumulation. This solodi characteristically carries a woodland of *Casuarina glauca*. The profile consists of a dark grey surface loam on a grey clay hardpan. The reaction is acidic: for example, at one site the surface had a reaction of pH 6.6 and the subsoil pH 6.0. This solodi type also occurs generally under similar conditions in the red brown earth zone.

The zone has been divided into three regions—

1. Swan littoral region of coastal sandhills, and clay flats adjacent to the range.
2. Darling peneplain region where gravelly soils are characteristic.
3. Frankland region: karri, jarrah and marri forest soils and wet heaths of the southern areas.

1.—SWAN LITTORAL REGION: 4,400,000 ACRES.

The west coast south of about 31°S is fringed by a littoral belt from 10 to 25 miles wide bounded on the east by the Darling escarpment or fault line. Granites, basic dykes and Precambrian metamorphosed sediments of the peneplain are sharply in contrast with the great depths of Tertiary and Mesozoic deposits of the littoral. These sediments form an artesian basin and bores have proved them to be in excess of 2,000 feet thick. Over much of the region, aeolian sand dunes, fixed by a sclerophyll woodland, cover the sediments and, unfortunately, provide but poor material for soil formation.

The climate is good; the average annual rainfall ranges from 30 to 40 inches, of which 80 per cent. falls in the winter period, and frosts are rare and seldom severe.

The vegetation may be described as a sclerophyll forest with an undergrowth of sclerophyll shrubs. Marri (*Euc. calophylla*) is generally characteristic of the better soils and jarrah (*Euc. marginata*) of the poorer types. Banksias, casuarinas and *Euc. Todtiana* grow on the poorest and most leached sands. Tuart (*Euc. gomphocephala*) characterises the coastal limestone areas.

The soils are best described in relation to three main sub-regions into which the Darling littoral region naturally falls.

a. *The talus soils.*

A narrow talus area forms the transition between the escarpment and the coastal plain. The slopes are generally not steep and the soils are generally gravelly—that is, they show a considerable amount of lateritic gravel

*The solodi is usually regarded as a solonised soil, or one which has been subjected to solonising influences, which has been acidified by leaching.

in the upper layers. Boulders of laterite have been reported in some localities. Grey sand forms the surface soil in some instances but the more general profile is a yellowish or greyish yellow gravelly sandy soil with a yellowish clay or gravelly clay subsoil. Reddish soils, as at Armadale, reflect the effect of special geological formations.

Pasture production and grape growing are the chief agricultural pursuits.

b. *Grey, grey brown and chocolate soils of the flats.*

The talus soils abutt abruptly on to the podsolised and slightly podsolised soils of the flats which consist of a belt of recent alluvial deposits some 130 miles long in a north-south direction and 4 to 7 miles wide. Prior to the provision of more adequate drainage the short coastal rivers flooded these flats and deposited layers of clay, sands and gravels as they overflowed their banks. Consequently, many of the stream channels are raised and the soils are forming on a complex and variable series of deposits.

The subsoil is characteristically a yellowish clay, often showing interposed layers of sands and gravels, and usually rests on a grey and red mottled stiff clay at a depth ranging from 6 to 10 feet. Considerable variation is observed in the surface layers which range from rich chocolate loams and grey brown sandy loams to leached grey sands more typically podsolised. Some areas are characterised by "claypans" or broad, shallow depressions perhaps one to two feet below the general level of the country. These greatly interfere with the development of the country.

The soils of this sub-region are among the most fertile in the State and are relatively rich in phosphate, potash and lime. The reaction usually ranges between pH 5 and pH 6 but samples between pH 4.5 and pH 5 have been examined. Table 1 gives a summary of the chemical composition of representative soils from Harvey, and the reactions of unlimed soils of the sub-region are indicated by the data in Table 2.

Development of this sub-region has been made possible largely by improved drainage to remove the excess winter water and the area will probably become the most intensively settled agricultural area of the State. Irrigation is being established over much of the area and rapid extension of the area watered is promised in the future as greater efficiency is attained in the present irrigation districts, and as new schemes are brought into being, either using the hills water or water pumped from the artesian or subartesian basin. In the northern part of the sub-region grape growing predominates and citrus, stone fruits and pastures are important. Pasture production, at present largely for dairying, is the chief industry in more southerly portions. Fat stock, horse breeding, citrus and potato production are industries of some magnitude.

c. *The Sandhill Soils.*

The coastal areas are notoriously sandy. For a distance of from 5 to 20 miles inland a sandhill formation, clothed with timber and heath, prevails and presents a generally uninviting range of soil types to the agriculturist.

These sands have apparently been blown inland from the coast.

The more inland soils are generally non-calcareous, probably as a result of a longer period of leaching, often exhibit evidence of buried profiles as a result of wind action, and carry a sclerophyll forest of jarrah and marri

TABLE 1.

Distribution Table showing the Composition of Samples from 23 Sites in in Citrus Orchards in the Harvey Irrigation Area. Sampled January, 1918, by the Department of Agriculture and analysed in the Government Chemical Laboratory. (Explosives and Analytical Department File 52/18.)

NUMBER OF SAMPLES IN EACH RANGE.

—	Total Nitrogen.								
Range (per cent. nitrogen) ...	Below ·01	·01–·03	·03–·05	·05–·10	·10–·30	·30–·50	·50–1·00	Above 1·00	
Surface soil	...	...	2	7	14	...	...	...	23
Subsoil 12 inches deep ...	1	13	6	3	...	...	...	...	23
Deep subsoil 30 inches deep ...	...	18	2	3	...	...	...	...	23
—	Phosphoric Oxide (P_2O_5). (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent P_2O_5)	—	Below ·01	·01–·02	·02–·04	·04–·06	·06–·08	·08–·10	Above ·10	
Surface soil	...	...	...	3	3	6	5	6	23
Subsoil 12 inches deep ...	...	...	1	5	12	5	...	...	23
Deep subsoil 30 inches deep ...	...	...	...	14	5	4	...	...	23
—	Potash (K_2O) (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent. K_2O) ...	—	·01–·03	·03–·05	·05–·10	·10–·30	·30–·50	·50–1·00	Above 1·00	
Surface soil	...	...	7	9	7	...	...	...	23
Subsoil 12 inches deep ...	...	1	8	14	...	...	...	...	23
Deep subsoil 30 inches deep ...	...	1	13	8	1	...	...	...	23

TABLE 1—*continued.*

—	Lime (CaO) (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent. CaO) ...	Below ·10	·10–·20	·20–·30	·30–·40	·40–·50	·50–·60	·60–·70	Above ·70	
Surface soil	...	4	4	5	5	2	3	...	23
Subsoil 12 inches deep ...	4	12	5	1	1	...	...	...	23
Deep subsoil 30 inches deep ...	6	13	3	1	...	...	...	...	23

TABLE 2.

Distribution Table showing the Reactions of Soils of the Harvey-Brunswick Irrigation Areas. (As far as is known these soils have never been limed.)

—	Number of Samples in each Range.									Total Number of Samples.
Range of pH Values	Below 4·8	4·8–5·0	5·0–5·2	5·2–5·4	5·4–5·6	5·6–5·8	5·8–6·0	6·0–6·5	Above 6·5	
Surface to 3 to 5 inches deep ...	1	7	9	17	27	16	8	4	...	89
Subsurface 3 to 5 to 12 inches ...	...	1	8	11	14	20	13	9	1	77
Subsoil 12 to 48 inches	...	1	2	2	...	7	4	3	1	20
Deep subsoil below 48 inches ...	...	2	5	4	6	4	4	3	3	31

associations. *Banksia grandis, B. Menziesii, B. attenuata, Casuarina Fraseriana* are typical small trees. The profile is more or less uniformly sandy and consists of a greyish surface sand on a yellow sandy subsoil. The depth of the surface horizon ranges from a few inches, when the grey is tinged with yellow, to several feet.

More highly leached soils occur in patches. These are white sands, often with humous coffee rock about the level of the water table, and usually carry a stunted vegetation of *Eucalyptus Todtiana, Adenanthos cygnorum,* etc.

The more coastal areas are generally calcareous at depth. Extensive deposits of forameniferal sands occur all along the western coast. These have been blown inland and by solution and precipitation have consolidated to form aeolian limestones. Fringing the coast, where the limestone or lime sand is often just under the surface, a heath vegetation usually occurs but further inland the lime has leached to greater depths—often many feet—and on these soils are found the valuable tuart (*Eucalyptus gomphocephala*) forests. The tuart soils are brownish to greyish on the surface. Where the limestone is within a few feet of the surface the subsoil is usually pinkish in colour but where a greater depth of soil occurs a brownish yellow colour characterises the subsoil.

These sands are very low in plant foods. Kessell and Stoate (1938) give the results of analyses which may be summarised as follows:—

—	Number of Samples in each Range. (p.p.m. in the dry soil.)							
Range ...	0–10	10–20	20–40	40–60	60–80	80–100	100–200	above 200
P_2O_5* ...	18	4	2	...	...	1	6	...
K_2O* ...	4	7	10	3	...	3	1	3

	(per cent. in the dry soil.)					
Range ...	below ·001	·001–·005	·005–·010	·010–·050	·050–·100	·100–·500
CaO* ...	4	6	2	9	4	2
Total nitrogen	4	7	4	10	3	...

	(pH value.)				
Range ...	below 5·0	5·0–5·5	5·5–6·0	6·0–6·5	6·5–7·0
pH	2	6	8	12	4

* Soluble in concentrated hydrochloric acid.

A characteristic of these soils is a concentration of calcium in the surface layers. For instance, the average CaO content of surface and subsurface samples from 10 sites reported by Kessell and Stoate (1938) is 0.183 per cent. and 0.086 per cent. respectively. Deeper subsoil layers are even poorer in calcium. Likewise, as is usual, nitrogen is richer in the surface layers. Phosphate shows a similar relationship but is less consistent; potash shows less tendency to surface segregation than the other constituents. Undoubtedly this surface concentration of plant constituents is due to the decomposition of leaves and litter from the vegetation. It is probably necessary to maintain a crop—forest or agricultural—on such soils to prevent the breaking of this plant nutrient cycle and the loss of valuable minerals by leaching and drainage from bare land.

In their studies on the growth of exotic pines, Kessell and Stoate (1938) find that the phosphoric oxide (P_2O_5) content of the soil is a good indicator.

Pinus radiata requires 400 p.p.m. P_2O_5 in the surface and subsurface soils or 300 p.p.m. to a depth of two to three feet for satisfactory growth.

Pinus pinaster requires a P_2O_5 content of not less than 150 p.p.m. for satisfactory growth. They find also that on the poor soils the pines respond to treatment with superphosphate in the early stages, and zinc sprays on young plants on certain soil types are curative of certain nutritional disorders.

Innumerable marshes, swamps and poorly drained basins occur in these sandhills and probably occupy about 5 per cent. of the total area. They have been described in some detail by Teakle and Southern (1937a, 1937b), who show that there are several types of which the following are the most important:—

(a) Acidic peaty sands and loams.

(b) Highly acidic colloidal peats.

(c) Marly peats.

In the Gingin and Dandarragan districts interesting intrazonal soils occur on Cretaceous chalks, greensands and sandstones. These are excellent pasture and lupin soils and form the basis of an important stock raising industry. A stock disorder of these districts, enzootic ataxia, has recently been shown by Bennetts and Chapman (1937) and Bennetts (1937) to be associated with a very low copper content in the liver and blood of affected animals and to be prevented by salt licks containing small amounts of copper sulphate.

The chief soils of the Gingin area have been mapped by Hosking and Greaves (1936), who show that a rendzina, the Gingin clay, the red coloured Whakea sand and the greyish Minjil sand are the chief types. While the light textured soil types were found to be low in plant nutrients, the heavy textured soils generally were well supplied with, and in some cases exceptionally rich in, phosphate and potash. The replaceable bases showed the clays to be of the calcium and calcium-magnesium types. Sodium was very low in the replaceable base fraction.

2.—DARLING PENEPLAIN REGION: 3,900,000 ACRES.

The region is essentially dissected granitic peneplain. The surface has been laterised and in the course of subsequent erosion much of the capping has been broken and disintegrated into a ferruginous gravel. This

ferruginous gravel occurs in practically all soils except in relatively small areas in the deeper valleys such as the Blackwood and Preston Rivers. The ferruginous gravel has influenced the soil forming processes and retarded the development of many podsolic characters. It has promoted the extension of the yellow colour of the subsoil into the surface layers. Where a light sandy surface overlies the gravelly layer, the bleached subsurface (A_2 horizon) and other podsolic features may be apparent.

The Darling peneplain is characteristically covered by the jarrah bush. On the more gravelly soils jarrah (*Eucalyptus marginata*) predominates, but where better soil conditions occur marri (*Euc. calophylla*) enters the association and often predominates. In the valleys, blackbutt (*Euc. patens*) is characteristic, and Clarke and Williams (1926) have observed wandoo (*Euc. redunca* var. *elata*) to be associated with the brown and chocolate soils on dolerite dykes in the escarpment area in the neighbourhood of Perth.

While it is impossible to describe one profile characteristic of the region the most important soil types generally show a yellowish clay subsoil, often gravelly and frequently showing a short fracture when being moulded. Grey and red mottlings frequently show in the deeper layers of the B horizon. The surface may be a yellowish grey gravelly sand to sandy loam or a grey sand with or without gravel. In some areas immature, granitic soils of low fertility are encountered and on the basic dykes and segregations, red acidic soils are usual and constitute the basis for much of the agricultural development.

Soil analyses reported by Kessell and Stoate (1938) show that the soils of this region range from very poor types, as were studied in the Pardelup area, to soils quite normal with respect to constituents other than phosphoric oxide. A summary of their data, treating all samples as units no matter what horizon of the profile they represent, is as follows:—

—	Number of Samples in each Range. (per cent. in the dry soil).									
Range	below ·01	·01 to ·03	·03 to ·05	·05 to ·07	·07 to ·10	·10 to ·20	·20 to ·40	·40 to ·60	·60 to 1·00	No. of Samples.
Total Nitrogen....	....	14	17	12	8	18	4	....	....	73
P_2O_5*	17	36	16	2	1	1	....	....	....	73
K_2O*	15	13	6	9	16	12	2	....	....	73
CaO*	12	13	9	2	4	15	13	2	2	72

* Soluble in concentrated hydrochloric acid.

Agriculturally, the region is developed principally for pasture purposes and horticulture. Subterranean clover grows throughout the region and is the basis of the dairying and sheep industries. Apples are by far the most important fruit crop. It is also the home of the jarrah forest which is being maintained in production under a vigorous forest policy.

3.—FRANKLAND REGION: 4,630,000 ACRES.

Along the south coast between Albany and Cape Leeuwin the average annual rainfall ranges from about 35 inches to 60 inches and the summer conditions are cooler and more moist than in any other part of the State. Certain vegetation associations (karri (*Euc. diversicolor*)) approach the rain forest and large areas of wet heath country occur.

The principal geological formations are the granitoid or gneissic rocks with extensive basic segregations, and poor sands many areas of which belong to the Plantagenet series. Basalts are reported in isolated places along the coast.

The coastal areas may be described as estuarine deposits of Plantagenet beds out of which rise "islands" of country rock. The wet heaths with shallow surface peaty accumulations have formed on the sands of the Plantagenet beds, and in shallow depressions or "lakes" various types of peaty deposits have developed. On the "islands" of country rock which are often of very considerable area, jarrah and marri forest formations occur where the soil are gravelly or highly podsolised. Where there is less gravel, less evidence of leaching and where basic segregations occur, karri forest is in evidence.

The inland areas of the region may be regarded as the break between the Darling peneplain and the coastal areas. Considerable dissection has taken place and the physiography is definitely immature. Lateritic and gravelly soils associated with jarrah and marri forest associations occur generally on the higher levels, and where erosion has exposed the country rock and in the valleys a karri association is usual.

The soils of the Denmark area, which have been described in detail by Hosking and Burvill (1938), may be taken as representative of the region. In this survey thirteen soil types, grouped in nine series, were identified and examined, and five groups of swampy, alluvial and other complexes were distinguished. Chemical analyses show the soils to be generally low in plant foods and quite variable. The highly leached types such as the Plantagenet, Kordabup and Kwilalup soils are highly acidic but the main soil types are more favourable in reaction as they generally range from pH 6 to pH 7.

A summary of these data is given in Table 3.

Analysis of the replaceable base fraction shows the soils to be more or less unsaturated and generally 40 to 60 per cent. of the total exchange capacity consists of hydrogen. Calcium is next in importance with a general range of 25 to 45 per cent. and magnesium is fairly high in the Koorundurup and Koorrabup series. Sodium and potassium are low in practically all cases. The analysis of the subsoil clays of Denmark soils generally shows a low silica: sesquioxide ratio (0.5 to 1.8) and a low silica: alumina ratio (0.7 to 1.9). In keeping with these facts, the base exchange capacity is very low as it generally averages about 15 milliequivalents per 100 gms. clay.

Hosking and Burvill (1938) have related the reddish and chocolate coloured soils of the Scotsdale and Koorundurup series, which are formed on basic rocks, to certain red soil types of the American Piedmont belt. The Wakundup and Koorrabup series appear to be related to the grey brown podsolic soils and the yellow soils of the eastern United States of America.

The occurrence of enzootic marasmus, a wasting disease of cattle and sheep in the Denmark district, led to intensive studies by Filmer and Underwood on the nutritional aspects and by Hosking and Burvill (1938) on the soils. Underwood (Underwood and Filmer, 1935) succeeded in demonstrating that cobalt deficiency was the cause of this disorder and the soil survey established the association of the Wakundup series with the incidence of the disease. Harvey (1937) collaterally showed that the cobalt content of the Wakundup series is low in comparison with recognised "sound" soils of the area and with soils of other districts. The surface soils of the Wakun-

TABLE 3.

Showing the Medial Values for Soil Reaction, and Nitrogen, Potash and Phosphoric Oxide content, of representative Soil Series of the Denmark Soil Survey (Hosking and Burvill, 1938.)

	pH.			Nitrogen (per cent. in dry soil).		Potash (K_2O) (per cent. in dry soil).		Phosphoric Oxide (P_2O_5) (per cent. in dry soil).	
Horizon	A_1	B	BC	A_1	A_2	A_1	A_2	A_1	A_2
Soil Series—									
Scotsdale	6·7	6·9	6·3	0·21	0·08	0·057	...	0·028	...
Wakundup	6·3	5·8	5·3	0·32	0·07	0·034	0·028	0·022	0·013
Koorundurup	6·1	6·0	5·3	0·17	0·06	0·058	0·099	0·012	0·007
Koorrabup	6·0	6·0	5·5	0·16	0·03	0·019	0·011	0·011	0·004
Kordabup, Kwilalup and Un-named	5·0	5·3	4·9	0·15	0·05	0·041*	0·038*	0·008*	0·005*
Plantagenet and Willbay ...	4·4	4·8	...	0·84	0·02	0·018	...	0·006	...

* Omitting the un-named sandy loam which is very rich in potash and much higher in phosphoric oxide than the other two series in this group.

dup series average 0.8 p.p.m. cobalt (11 samples) in comparison with 3.8 p.p.m. cobalt (6 samples) in the generally sound Scotsdale series, and 9.6 p.p.m. cobalt—range 0.5 to 40.0 p.p.m. (24 samples)—for soils representing other parts of the State where cobalt deficiency in stock has not yet been recognised.

Unpublished data regarding the soils of the Manjimup area show that the main profile features are similar and the principal soil types closely resemble those of Denmark.

Valuable areas of peaty swamp land occur in the eastern coastal parts and are being used for potatoes, truck crops and pastures. The swamp lands fall into three main types: (a) marly peats, (b) acid peats and sandy peats. The modal reaction of these soils is about pH 4 but considerably higher degrees of acidity have been reported (Teakle and Southern, 1937), (c) greyish acid muck soils with a modal reaction range of pH 4 to pH 5.

Agriculturally, the region is developed for dairying, fruit growing, potatoes and truck crops, and is proving very satisfactory for tobacco on certain valley soil types in the Manjimup, Pemberton and Walpole districts. Sheep raising for the meat market offers promising returns. Forestry is of considerable importance on account of the valuable karri timber. The propitious climate renders the prospects for further development very satisfactory, but success will depend upon the solution of nutritional problems with stock and plants. The necessity for cobalt to maintain the health of stock on certain soil types is well known, and copper and manganese in addition to the usual fertilising ingredients are proving valuable adjuncts for potatoes, pastures, and truck crops on certain soil types. Drainage is required on much of the wet heath country.

B.—ZONE OF RED BROWN EARTHS OF THE EUCALYPTUS-ACACIA WOODLANDS—27,460,000 ACRES.

The red brown earths defined by Prescott (1931) occur as a zone between the highly leached or podsolised soils and the pedocals represented by the grey and brown calcareous, solonised soils. The average annual rainfall ranges from 15 to 25 inches, is of winter incidence and sufficient leaching power to have removed calcium carbonate and soluble salts from the subsoil except in the heaviest soil types. The typical profile consists of a brown to red brown surface or A horizon with a reddish subsoil or B horizon showing clay accumulation. Calcium carbonate is observed in the deeper subsoil in some instances in Western Australia, but is much less common than in the red brown earths of the Eastern States. Generally the subsoil is non-calcareous but slightly alkaline to alkaline in reaction so that the colloids should be almost base saturated. The surface soil is generally neutral to slightly acidic in reaction. (See Tables 5 and 6 below.)

Within the red brown earth zone, however, extensive areas of normal grey and grey brown soils with yellowish or greyish subsoils occur and reflect greater leaching and, in many cases, different parent materials. Furthermore, the greyer soil types are far more prevalent in the southern part of the zone than in the northern regions—apparently the result of a temperature effect as red colours appear to develop more readily under higher temperatures. Greyer soils develop on the more acidic rocks and on pipeclay formations which occur in the southern areas. These soils generally resemble the browner types in reaction values.

Lateritic gravel is common throughout the zone. It occurs in massive form on the mesas which carry mallet (*Eucalyptus astringens*), wandoo (*Euc. redunca* var. *elata*) and poisons (*Oxylobium, Gastrolobium*), but is generally in the form of gravel in the more eroded areas. It is more abundant at the higher levels.

This lateritic gravel occurs, but is uncommon, in the brown and red brown soils and in many of the grey soils forming on country rock of similar strata. In some cases this is obviously adventitious material from the original laterite capping but, where drainage is somewhat impeded, leading to periodic waterlogging, a certain amount of ferruginous gravel appears to be forming in the subsoil at the present time as a result of normal pedogenic processes. Similar occurrences of ferruginous gravel have been observed in the Cowra District, New South Wales, in New Zealand, etc. (See discussion on p. 128.)

Soils of the lateritic gravelly material are generally more yellowish in colour and often exhibit shades of pink, particularly where what appears to be a lithomarge is exposed. Wandoo and sclerophyll scrub are typical of these types, which occupy practically a continuous belt on the wetter fringe of the zone.

A small area of a heavy textured black earth, with a calcareous subsoil, has been observed on a highly basic dyke in the Pallinup area and represents an intrazonal type.

Reference has already been made to the occurrence in this zone of solodi soils on saline flats subject to inundation during the winter months. These soils are slightly acidic in reaction, are characterised by a grey clay hardpan and carry a woodland of *Casuarina glauca.*

Deep sandy soils are frequently associated with a woodland of *Casuarina Fraseriana.*

The principal geological formations of the zone are granitic rocks and gneisses with basic dykes. In the southern areas the Stirling Range quartzites affect the soils and there is evidence of other metamorphosed rocks which modify the course of soil formation. The country is typically hilly —rounded hills are characteristic, but many flat topped mesas occur in the southern regions.

Most typical vegetation associations are york gum (*Euc. foecunda* var. *loxophleba*) and jam (*Acacia acuminata*) woodlands which are well grassed and are the most prized farming lands of the zone. York gum grows on the stronger and heavier textured soils and jam on the lighter soils. Wandoo sclerophyll woodland is common south of Moora and constitutes a region. As has been mentioned, mallet is typical of the mesa slopes south of Beverley. Salmon gum (*Euc. salmonophloia*) and morrel (*Euc. longicornis*) woodlands occur in a number of places and are of considerable agricultural value in the Moora, Wagin and Katanning districts. South of Katanning morrel is known as "poot" and grows on the strongest farming lands.

Sand heaths are common throughout the zone, particularly north of Northam. Deep sandy types, gravelly types and sandy types with a yellowish gravelly and clayey subsoil occur. The latter is of considerable agricultural value if liberally dressed with superphosphate. Poison plants are often a trouble with stock, particularly in the wandoo woodlands.

Agriculturally, the zone is most important for stock raising in conjunction with cereal production. Sheep, fat lambs, pigs, cattle and horses are raised: oats for stock feed, and wheat and oats for hay and grain are produced throughout the area. First early and midseason subterranean clover (*Trifolium subterraneum*) do well in the wetter portions, lucerne for grazing is grown in the south, and wimmera rye grass (*Lolium rigidum* var. *subulatum*), *Phalaris tuberosa* and perennial veldt grass (*Ehrharta calycina*) are valuable supplements to the native grasses (*Festuca* spp., *Stipa* spp., etc.).

Of recent years an undesirable weed known as crow's foot (*Erodium botrys* and spp.) has invaded many sown pastures, particularly subterranean clover pastures, and is causing considerable reduction of grazing value on some farms.

Stock water is readily obtained in wells in the northern areas but dams are relied on to a great extent in the south.

Most districts suffer from the development of salinity in creeks and low-lying areas. This affects the supply of stock water and renders a small amount of country unsuitable for cultivated crops. The problem results from a rise in the salt water table and the development of saline springs following the clearing of the timber, which greatly increases the amount of percolating subsoil water.

The concentration of the rainfall in the winter months, with resultant waterlogging of many soil types especially in wet seasons, presents a problem in farm management. The months of June and July are generally excessively wet, and with low temperatures prevailing, pasture and crop growth is greatly retarded until the spring flush. Means have not yet been found of accelerating growth during the cold, wet winter months.

The red brown earth zone has been subdivided into five regions.

*4.—DWARDA REGION: 4,600,000 ACRES.

The Dwarda region is essentially a wandoo (*Euc. redunca* var. *elata*) woodland associated with lateritic gravelly soils and is really transitional between the red brown earths proper and the more highly leached or podsolised soils. The surface soils are generally slightly acidic, grey or yellowish grey in colour, and sandy or gravelly in nature, and have a yellowish or greyish subsoil. This subsoil is generally gravelly and shows an accumulation of yellowish and greyish gritty clay, often showing red mottlings. Many of the soils are very shallow and immature.

Waterlogging is frequently prolonged during the winter months. This condition apparently gives rise to a siliceous cement as the subsoil cements badly on drying out in the summer.

The Northern portion of the region is undulating to hilly, but south of Katanning the country is relatively flat. Many of these flats show poorly drained portions on which swamp yate (*Euc. occidentalis*) is characteristic. Yate (*Euc. cornuta*) grows on the higher land. A typical profile in these areas shows the following features:—

Surface:—Brownish grey gritty sand to sandy loam.

Subsoil:—Pale yellow to yellow sandy loam to gritty and sandy clay showing red mottling with depth. Cements badly on drying out in the summer.

* The regions are numbered in sequence 1-33.

Analyses of samples of soils from Cranbrook and which show these features are given in Table 4. Brown and red brown soils of heavier textures occur in patches throughout the area. These show the more typical red brown earth colours and are frequently associated with basic dykes and segregations.

This area south of Katanning could well be described as a sub-region. It is well known for the production of stud merino sheep.

The region is primarily suited to pasture and forage production with attendant stock raising and to forestry—particularly for the growth of mallet (*Euc. astringens*) and wandoo for tannin supplies. Many portions of the area are badly affected by poisons of which box poison (*Oxylobium parviflorum*), York road poison (*Gastrolobium calycinum*), cluster poison (*G. microcarpum*), sandplain poison (*G. oxylobioides*) and bullock poison (*G. trilobum*) are commonest and most serious hindrances to stock raising. The soils are naturally of low fertility chemically but after being built up with subterranean clover and superphosphate are proving more suitable for grass establishment.

TABLE 4.

Analyses of Soils from the Cranbrook Area. The country originally carried Wandoo, Yate (Euc. cornuta), Shrubs, Grasses, etc.

Serial. No.	Depth inches.	Organic Carbon.	Total Nitrogen.	Phosphoric Oxide (P_2O_5) sol. in conc. HCl.	Phosphoric Oxide (P_2O_5) sol. in 1% citric. ac.	Potash (K_2O) sol. in conc. HCl.	Potash (K_2O) sol. in 1% citric. ac.	pH.
		%	%	%	%	%	%	
A2065 ...	0–2½	4·14	0·190	0·026	0·0013	0·075	0·019	6·50
A2066 ...	2½–14	0·32	0·017	0·014	0·0008	0·039	0·0057	6·76
A2067 ...	14–18	0·19	0·018	0·011	0·0008	0·171	0·0044	7·09
A2068 ...	0–2½	2·78	0·122	0·019	0·0033	0·079	0·0216	6·50
A2069 ...	2½–6	0·38	0·014	0·008	0·0008	0·033	0·0068	6·64
A2070 ...	6–10	0·34	0·014	0·015	0·0010	0·098	0·0043	6·03
A2071 ...	0–2½	0·99	0·062	0·038	0·0194	0·105	0·0131	6·14
A2072 ...	2½–5½	0·29	0·011	0·014	0·0020	0·072	0·0039	6·54
A2073 ...	5½–9½	0·19	0·022	0·005	0·0008	0·184	0·0064	6·84
A2074 ...	0–2	2·98	0·196	0·045	0·0041	0·222	0·0202	6·60
A2075 ...	2–4	0·70	0·043	0·020	0·0006	0·176	0·0109	7·19
A2076 ...	4–8	0·47	0·031	0·014	0·0010	0·206	0·0069	7·02

5.—IRWIN REGION: 7,950,000 ACRES.

The red brown earth zone north of Moora exhibits a number of distinct ecological and soil characteristics. As compared with other regions of the zone, the soils generally are browner, and grey types are far less extensive. Calcium carbonate accumulation in the deeper subsoil, while not general, is far more common than in the Avon region. Wandoo is a less general

feature of the timber and the flat topped mesas are uncommon, except in the confines of the Geraldton area where flat topped ranges of Jurassic age are prominent land marks. Sand heath formations are common and extensive—for instance, the sand heath on the Jurassic plateau west of the Midland Railway stretches with few breaks from Moora to north of the Geraldton-Mullewa line. In the vicinity of Mingenew is an occurrence of blue bush steppe on heavy grey clay soils forming on Jurassic shales. The north-eastern portion of the region is characterised by loose sand heaths and strips of reddish soils forming on sedimentary rocks. These soils are particularly liable to damage by wind action unless properly managed under cultivation.

Generally, however, the zonal soil characters are similar to those of the Avon region and York gum and jam woodlands are the most typical associations. Salmon gum woodlands occur in several districts, for example, Moora, Carnamah and Three Springs, and are associated with strong agricultural soils which are generally calcareous in the deeper subsoil.

The reactions of representative soils of the Irwin region are indicated in Table 5. Both surface and subsoil samples are generally slightly alkaline to alkaline in reaction.

Apart from the areas of poor sandy and gravelly country which are associated with laterite and quartzitic rocks, the soils of the Irwin region are among the most productive in the State. The region is excellent stock country and highly productive of cereal crops. Improved pastures are increasing and in the coastal areas lupins have proved very valuable for stock purposes. Before the advent of superphosphate, the fertile brown soils of the Irwin and Greenough River valleys in the vicinity of Dongara and Geraldton respectively were popularly described as the granaries of the State. These soils are still valuable agriculturally but, in common with other soils of the region less favourably supplied with available phosphate, are now generally responsive to superphosphate.

6.—AVON REGION: 6,700,000 ACRES.

The Avon region is essentially an area of brown and grey soils carrying York gum and jam woodlands. These may be regarded as normal soils. Areas of brown and greyish soils carrying salmon gum, gimlet and morrel occur in isolated patches throughout the bulk of the region. In the south, in the Gnowangerup district, morrel or poot (*Euc. longicornis*) is very common on the better red-brown earth soils and grows in association with York gum and wandoo.

On the sandy heath country, which occurs in restricted areas throughout the region, the soil is a greyish sand with a yellowish subsoil, often with laterite gravel. Wandoo occurs generally throughout the region but more particularly on the grey sandy and gravelly soils and on the light grey gritty soils with a yellowish or a white pipeclay subsoil. The lateritic gravelly soils of the breakaways are of low value agriculturally but carry important mallet (*Euc. astringens*) thickets

Associated with these gravelly soils of the mallet slopes are frequently found powdery, gravelly soils, generally greyish in colour. In the virgin state they carry morrel (*Euc. longicornis*), mallet, wandoo, etc., and are generally acidic in reaction (pH. 4.4 to pH 6.5). These soils frequently fail to support the growth of cereals unless 14 to 28 pounds of manganese sulphate

TABLE 5.

Distribution table showing the reactions of Soil samples from sites in the Irwin Region which show little or no influence of laterite.

—	Number of Samples in each Range.											Total Number of Samples.
Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface (A horizon)	...	...	...	...	1	7	6	14	9	4	4	...	45
Subsoil (B and B–C horizons) ...	...	...	...	3	5	3	10	13	28	14	14	3	93

Table includes serial Nos. A (32–45, 50–53, 71–87, 147–175, 206–209, 313–332, 2207–2213, 2226–2236, 2243–2247, 2251–2255) and various samples from Indarra.

per acre is applied with the superphosphate. Wild (1934) has described work on these soils and Adams (1937) indicates that peas are less susceptible to the manganese deficiency than are the cereals.

The following distribution table (Table 6) shows the reaction of surface and subsoils from sites showing little or no influence of laterite. It is to be noticed that the surface soils are generally in the range of pH 6.4 to pH 7.6, but the subsoils are typically more alkaline, generally falling in the range pH 8.0 to 9.0. These subsoils are typically non-calcareous in Western Australia but the clays must be base saturated according to the usual standards.

The soils more or less influenced by lateritic formations are generally more acidic.

The Avon region is noted for its stock and cereal production. A large number of high-class Merino studs are located in the region; some of the highest wheat yields of the State have been recorded; and cereal hay is an important industry in some centres. Dairying and pig raising are important adjuncts in many districts, subterranean clover and burr trefoil (*Medicago denticulata*) are important leguminous pasture plants and *Phalaris tuberosa*, Wimmera rye grass, *Bromus* spp., etc., supplement the native grasses.

7.—STIRLING REGION: 2,800,000 ACRES.

South and east of the Avon region is a belt of country in which a proportion of the soils are affected by certain little known geological influences. These have given rise to grey, sometimes grey-brown, types of clayey soils which carry dense thickets of stunted eucalypt known as moort (*Eucalyptus platypus*). In the field, the soils appear to be solonised and may be either acidic or alkaline in reaction. Only one site in every four examined by the writer showed calcium carbonate in the subsoil. Furthermore, it was observed that the deeper layers of the subsoil were more acidic than the upper layers. Associated with these soils are the more typical red-brown earths, and extensive areas of light, sandy mallee country and sand heaths the soils of which are more or less acidic in reaction and of low inherent fertility.

The reactions of soil samples taken to represent the so-called moort country of this region are given in Table 7, and in Table 8 are given the chemical analyses of soil samples collected in 1918 by Dr. G. L. Sutton to represent this type of country.

When first developed for wheat growing about 1917, yields generally were most disappointing and investigations failed to determine the cause. The chemical work reported indicated no abnormalities. This led to the use of these lands for stock raising and the treatment has been effective in greatly improving the soil conditions for the growth of wheat. Wheat growing on these lands is now being successfully practised in many instances. The climate is good and with the use of superphosphate, perhaps such ameliorants as gypsum which are useful for solonised soils, and the establishment of pastures such as wimmera rye grass the region should become an important mixed farming area of the State.

8.—EYRE REGION: 5,410,000 ACRES.

Along the south coast, eastward from the Albany district, is a strip of sand heath country 20 to 30 miles wide and broken only by a number of river valleys which drain the hinterland and flow after the heavier rains.

TABLE 6.

Distribution table showing the reactions of Soil samples from sites in the Avon Region which show little or no influence of laterite.

—	Number of Samples in each range.												Total Number of Samples.
Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface (A horizon)	...	1	...	7	9	15	14	11	6	5	2	...	70
Subsoil (B and B–C horizons) ...	2	1	5	5	4	8	11	4	14	41	37	14	146

(Table includes serial Nos. A (1, 5, 6, 9–14, 16–18, 243–7, 346–381, 384–387, 397–401, 2182–2185, 2323–2327) and samples from the Beegenup soil investigation (eliminating surface crusts and samples below 4 feet).)

TABLE 7.

Distribution Table showing the reactions of Soil samples from sites in moort (Euc. platypus) country in the Stirling region and adjoining portions of the Avon region.

—	Number of Samples in each reaction range.												Total Number of Samples.
Reaction Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface ...	...	...	...	1	3	1	3	2	1	1	...	...	12
Subsoil ...	2	2	3	1	1	4	...	2	7	5	2	4	33

Serial numbers considered: A384–396, 402–430, 435–437.

TABLE 8.

[illegible]

Sample.	Colour.	Depth. Surface.	Depth. Subsoil.	Nitrogen. Surface.	Nitrogen. Subsoil.	Phosphoric Oxide. Surface.	Phosphoric Oxide. Subsoil.	Potash. Surface.	Potash. Subsoil.	Lime (CaO). Surface.	Lime (CaO). Subsoil.	CO_2. Surface.	CO_2. Subsoil.	NaCl. Surface.	NaCl. Subsoil.
		inches.	inches.	%	%	%	%	%	%	%	%	%	%	%	%
1	Grey ...	0—4	4—8	·28	·084	·04	·015	·052	·102	·64	·154	·146	·070	·005	·010
2	Red ...	0—9	9—18	·095	·073	·021	·011	·245	·259	·101	15·46	1·10	14·65	·0033	·059
3	Grey ...	0—3	3—18	·157	·063	·030	·019	·075	·066	·48	·087	·43	·14	·0033	·030
4	Grey ...	0—9	9—18	·095	·028	·018	·012	·35	·28	1·00	4·18	·73	8·19	·033	·15
5	Grey ...	0—9	9—18	·084	·05	·023	·026	·34	·125	·168	·21	·23	·58	·030	·069
6	Grey ...	0—7	7—18	·112	·084	·026	·020	·32	·572	·34	1·09	·040	2·99	·013	·036
7	... ...	0—6	6—18	·095	·078	·041	·019	·100	·049	·067	·059	...	...	·180	·020
15	... ...	0—9	9—18	·067	·042	·020	·022	·039	·042	·129	·022	...	...	·0066	·0099
25	... ...	0—9	9—18	·078	·048	·021	·014	·061	·093	·218	·168	...	...	·0066	·0066
35	... ...	0—9	9—18	·067	·034	·017	·013	·015	·060	·137	·033	...	...	·0099	·0099
45	... ...	0—9	9—18	·129	·053	·027	·011	·088	·115	·478	·078	...	...	·039	·013
12	Grey ...	...	...	·056	·017	·04	·036	·472	·51	·130	·571	·55	·96	·125	·175
13	Brown	...	...	·034	·017	·038	·028	·486	·51	·197	6·94	1·04	7·90	·010	·013
14	... ...	...	...	·034	·028	·016	·011	·18	·26	·15	5·12	·46	6·48	·005	·013
15	... ...	...	...	·095	...	·041	...	·100	...	·067	...	·068	...	·180	...
16	... ...	...	...	·078	...	[illegible]	...	·049	...	·059	...	·072	...	·020	...

This country is of the laterite type and the typical profile is a grey sand of variable depth on a yellowish subsoil. The subsoil may be sandy or a yellow clay or gravelly clay. A description of two profiles from the Esperance District has been given by Teakle and Southern (1936). It is shown that these soils are generally low in plant foods, the clay has a very low base saturation capacity (15 to 20 milliequivalents per 100 gm clay), and the silica:sesquioxide ratio is low (1.42).

Information given in this paper and the results of analyses of samples from 19 other sites on the Esperance plain show the soils to be acidic—generally in the pH 5 to 6 range in the surface and somewhat less acidic in the subsoil. The situation is illustrated in Table 9.

TABLE 9.

Distribution Table showing the Reactions of Soils of the Eyre Region.

——	Number of Samples in each Range.					
Reaction range, pH.	4·8–5·2.	5·2–5·6.	5·6–6·0.	6·0–6·4.	6·4–6·8.	Total.
Surface ...	2	12	3	3	1	21
Subsoil ...	1	...	4	6	2	13

Numerous small swamps occur in the depressions and generally carry a dense tree formation principally of paper bark (*Melaleuca pubescens*) and shrubs.

The "normal" zonal soils occur along the valleys where the country rock has been exposed. From descriptions received these are of the red-brown earth type and are generally the basis of the scanty agricultural or pastoral development of the region.

The coastal fringe is granitic, and calcareous sands blown inland for a few miles form a series of sandhills and aeolian limestones, usually fixed by a littoral vegetation association, with intervening swamps and lakes.

The region is as yet practically undeveloped. However, the rainfall is generally adequate and well distributed and the soil types with a clayey subsoil or a somewhat loamy texture promise to be useful for pasture production. With adequate fertilisation it is possible to grow pastures of rye grass and clovers, and such crops as lupins and Tangier peas. With the development of the stock industry in the heavy textured country to the north, it is likely that this land will be a valuable complementary area in which summer feed and adequate water supplies are available.

C.—ZONE OF GREY AND BROWN CALCAREOUS, SOLONISED SOILS OF THE LOW RAINFALL EUCALYPTUS WOODLANDS—73,100,000 ACRES.

In the Eastern States the grey and brown calcareous, solonised soils typically carry a vegetation of stunted eucalypts popularly known as "mallee." The term mallee indicates a habit of growth of certain eucalypts: a habit of growth consisting of a number of stems, generally less than 4 inches in diameter, arising from an expanded crown or mallee "root." The plants are generally stunted but may reach 30 to 40 feet in height in the

case of the so-called giant mallees. Some species of eucalypts are typically of this habit and some other species exhibit both mallee and tree forms. For instance, *Eucalyptus oleosa, Euc. dumosa* and *Euc. gracilis* are typically mallees in the Eastern States but in Western Australia both forms are common and important in ecological associations.

Prescott (1931) recognised the soils of the mallee associations in the Eastern States as forming a new world group and proposed the name "mallee" soils for it. While the mallee soils of the Eastern States are normally associated with mallee vegetation associations, in Western Australia the typical "mallee" soils are associated with a sclerophyll eucalyptus woodland comprising chiefly such trees as salmon gum (*Eucalyptus salmonophloia*), gimlet (*Euc. salubris*), morrels (*Euc. longicornis* and *Euc. melanoxylon*), ribbon bark (*Euc. dumosa*), redwood (*Euc. oleosa* var. *transcontinentalis*), etc. The soils carrying mallee associations in Western Australia are generally of inferior quality as compared with the woodland soils, and intermediate between the sand heaths and the woodlands. In fact, in some districts the soil and vegetation associations constitute a catena comprised of a sequence consisting of soils of salt lake or salina flats, of valley woodland associations, of mallee associations on the slopes, and of sand and gravel heaths on the highlands. To Western Australians, therefore, the term "mallee" has no such general significance as in the Eastern States and a descriptive term is proposed as more appropriate for the zone in Australia than the concise term used by Prescott.

Furthermore, in Western Australia, normal soils of this zone are not generally related to sandhill formations, and Tertiary deposits are known to occur only in certain of the south-eastern areas—for example, the Fitzgerald region. The most prevalent surface geological strata are probably Precambrian sediments of the Whitestone series type (Forman, 1937), outcropping granitic rocks, and ancient valley deposits. The soils on these geological materials are generally very stable and show far less evidence of wind erosion. The sand grains in the mallee and woodland soils of most of the area are sharp and angular and offer greater resistance to wind action than the rounded grains of the soils on Tertiary sediments, as in the Salmon Gums district. For this reason it is probable that the soils of this zone in Western Australia are generally less disturbed than in the Eastern States and exhibit more faithfully the influence of the climatic, geological and biotic factors on the course of soil formation.

Again, in Western Australia there is no distinct "grey and brown soil" zone associated with a savannah association as described by Prescott (1931, p. 67) for the lower rainfall areas of the Eastern States and the north of Western Australia. Heavy textured grey and brown soils do occur in the so-called "mallee" zone of Western Australia. They typically carry a gimlet (*Eucalyptus salubris*) woodland, and typically show crabhole structures; the subsoil is calcareous, the clay is a magnesium-sodium complex and frequently shows slight gypsum accumulation. As these soils are inseparable except as soil types from the other soils of this zone in Western Australia, they are regarded as being of the same zonal soil group. Consequently the zone may be very appropriately designated "grey and brown calcareous, solonised soils."

Some of the soil types of this zone, more particularly the greyer soil types with a light textured surface and a clay subsoil, closely resemble certain solonetz soils described by American workers. The solonetz soil is

typically an intrazonal type and usually occurs as "slick" spots or small areas 4 to 15 feet across with the surface 6 to 15 inches below the general ground level (Kellogg, 1934). General occurrences of soil series with similar solonetz profiles are reported from California, but Nikiforoff (1937) considers these to be primarily the result of geological stratification and not pedogenic processes. It may be asked whether certain of the solonetz soils of Western Australia are not also the result of geological stratification. In the opinion of the writer there is little evidence to support this application of Nikiforoff's hypothesis.

It is thought that the Australian solonised soils, which assume zonal proportions, are the product of pedogenic processes. They form on a variety of geological horizons—Precambrian igneous and metamorphic materials, Tertiary marine and lacustrine deposits, alluvials, etc.—and appear to be the result of climatic and biotic factors. The eucalyptus woodland is the typical plant association and the soils form under a light rainfall, of low leaching powers, which annually deposits 15 to 30 pounds of salt per acre as cyclic salt (Prescott (1931), Teakle (1937)). The profile characters show no evidence of stratification except that to be expected from pedogenic forces.

In common with other zones of the south-western portion of the State, a very considerable proportion of the zone, except in the Zanthus region, consists of heath and scrub soils largely of lateritic origin. These soils are sandy or gravelly in nature, acidic in reaction and low in plant foods and generally occupy the higher levels of the country. The main formations appear to range from 100 to 500 feet above the valley floors. On these higher levels, where the sands and gravels do not occur, or have been eroded, eucalyptus woodlands and mallee associations appear. The soils are closely related to the valley types but the vegetation associations often include redwood (*Eucalyptus oleosa* var. *transcontinentalis*) as an important tree.

The rainfall of this zone ranges from 10 inches to 15 inches per annum and the Meyer ratio from 25 to 65. Approximately 70 per cent. of the total rain falls in the May-October season. Temperatures are mild in the winter and hot in the summer.

The influence of the rainfall is quite apparent as one proceeds from the higher to lower rainfall parts of the zone. The higher rainfall soils are characteristically greyer in colour and the sandy surfaced types exhibit more or less typical solonetz structure. An extreme example of this structure observed in the Scaddan district has recently been described by Burvill and Teakle (1938). As the average annual rainfall drops below 13 to 14 inches the soils become browner and are typically of a red brown colour.

Over one million acres of country in this zone have been mapped according to standard soil survey methods and some 34 soil series recognised. The chemical work has not yet been completed but is sufficiently advanced to have established the following general characteristics.

This work shows that the following profiles may be regarded as representative of the zone:—

(a) Brown to red brown neutral sandy loam to sandy clay loam resting on a brown to red brown calcareous and alkaline sandy clay subsoil—salmon gum and gimlet woodlands.

(b) Grey to grey brown sand with a bleached subsurface (A_2 horizon), resting abruptly on a grey to olive brown calcareous and alkaline

sandy clay subsoil—salmon gum and redwood woodlands, mallee associations.

(c) Grey to brown powdery, calcareous sandy loams and loams on a fawn to red brown calcareous and alkaline subsoil—morrel woodland.

(d) Grey clay loams on calcareous and alkaline grey clay subsoils—certain gimlet woodlands.

(e) Red brown sandy loams with siliceous hardpan impregnated with calcium carbonate in the subsoil—york gum woodlands of the northern portions.

(f) Brown and red brown non-calcareous sands and sandy loams of the granitic outcrops—jam (*Acacia acuminata*) and york gum mallee (*Eucalyptus foecunda*) associations.

(g) Grey on yellow sands; grey and yellow sand with a yellowish gravelly clayey subsoil; greyish and yellowish gravelly sands and gravels—heath and wodjil (*Acacia* spp.) associations.

The mallee and woodland soils are typically calcareous and alkaline in the subsoil, are generally rich in potash and extremely low in phosphate. The replaceable bases of the A horizon are of the calcium type but in the subsoil magnesium and sodium comprise about 70 to 80 per cent. of the total replaceable bases. Magnesium usually predominates but sodium is always high and sometimes exceeds the magnesium fraction. Organic matter and nitrogen are typically low and are highest in the morrel woodland types. Teakle and Burvill (1930 a and b) have shown that the nitrate-nitrogen status of the cultivated salmon gum and gimlet woodland soils as represented by the Merredin Agricultural Research Station is quite high.

The woodland and mallee soils are generally slightly saline in the subsoil. In the virgin state, in the agricultural areas, the second foot would be expected to contain 0.15 to 0.25 per cent. salt (sodium chloride) and a somewhat higher concentration would be found at lower depths. In the more arid portions of the zone and in the Fitzgerald region the concentration of salt in the subsoil is higher and will generally range from 0.25 to 0.50 per cent.

A feature of particular pedological interest is a strongly acidic layer which is commonly encountered at a depth of 6 to 10 feet. The calcareous subsoil ends more or less abruptly and gives way to this red and grey mottled stiff, sandy clay which generally ranges in reaction from pH 4 to pH 5. Occurrences have been observed in the Lake Brown and Lake King areas and the horizon appears to be general in the Salmon Gums district. Mention has already been made of this horizon in the Scaddan series by Burvill and Teakle (1938). Mineralogical examination of the fine sand fraction of this profile by Dr. Carroll showed the clay minerals to be essentially the same in the calcareous subsoil and in the acid clay horizon. Chemical analyses of this and other profiles of the Salmon Gums district show the silica : sesquioxide ratios of these layers to be similar. Furthermore, the coarse sand : fine sand ratios generally show no major changes between the different horizons. The replaceable base fraction is particularly interesting in that it is practically devoid of calcium but contains a preponderance of magnesium and sodium which together total about 90 per cent. of the fraction. The total replaceable base fraction in this layer amounts to about 30 milliequivalents per 100 grams of clay as compared with about 70 milliequivalents in the B horizon. Pertinent information is given in Table 10.

TABLE 10.

Replaceable Bases of Representative Soils in the Grey and Brown Calcareous, Solonised Soil Zone.

Serial No.	Soil Type.	Locality.	Depth.	pH.	Clay per cent.	Total Replaceable bases m. eq. per 100 gm. soil.	Percentage of Total Bases.			
							Ca.	Mg.	K.	Na.
			inches.							
A598	Wallambin sand	Wilgoyne	17–31	8·3	45·7	19·78	30	36	7	27
A608	Welbungin clay	Wilgoyne	1–6	8·2	49·4	27·55	37	40	4	19
A610*	... ...	... ...	15–37	8·1	44·6	22·53	22	45	2	31
A771/2 ...	Kumarl clay	Kumarl	0–5½	7·9	43·7	30·23	50	33	5	12
A774	... ...	... ...	13–24	7·8	45·9	26·58	24	40	7	29
A777	... ...	... ...	59–105	3·5	59·9	20·20	*nil*	50	7	43
A791/2 ...	Beete calcareous sandy loam	Kumarl	0–8½	7·9	23·4	24·38	44	34	8	14
A794	... ...	... ...	14–32	8·2	29·7	17·67	10	37	15	38
A799	... ...	... ...	96–114	4·0	49·0	16·04	*nil*	43	11	46
A781	Circle Valley sand	Kumarl	14–30	7·9	29·5	17·56	16	40	6	38
A787	... ...	... ...	96–114	5·7	26·6	8·30	*nil*	51	7	42
A499	Milarup powdery, calcareous loam	Lake Kathleen	0–9	8·2	20·9	31·3	34	30	15	21
A502	... ...	... ...	22–41	8·6	35·3	16·91	11	27	22	40
A466	Pallarup sand	Lake King	0–6	7·6	5·0	7·21	42	40	6	12
A468	... ...	... ...	14–27	8·2	39·3	22·25	15	34	16	35
A186	Merredin loam	Merredin Research Station	0–4	6·7	20·8	13·13	43	46	6	5
A189	... ...	... ...	18–28	8·6	48·8	23·58	25	43	6	26

* Gypsum present.

The association of certain eucalypts, for example, *Eucalyptus oleosa*, *Euc. longicornis*, *Euc. melanoxylon*, *Euc. gracilis*, *Euc. Flocktoniae* and *Euc. conglobata*, etc., with surface accumulation of calcium carbonate is suggestive of the power of certain vegetation associations in the gathering and concentration of soil constituents in the surface layers. As there appears to be no evidence of geological layering and the clays appear to be essentially the same throughout the profile it is postulated that the vegetation is responsible for the removal of calcium from and acidification of this deep horizon. The calcium absorbed would be deposited on the surface with fallen leaves, bark, etc., and on the death of the trees. Under the light rainfall conditions the calcium would accumulate in the B horizon as calcium carbonate. A similar effect of vegetation on the building up of soils in certain constituents, particularly lime and nitrogen, has been observed by Alway and his co-workers (1933 a, b, c) in Minnesota. The broad leafed trees, maple and bass-wood, were found to produce a forest floor layer almost 5 times as rich in lime and up to twice as rich in nitrogen as did jack pine and Norway pine. In New Zealand workers have observed a similar difference in effect between various vegetation associations.

On the basis of the predominance of grey or brown soil colours, the geology, topography, vegetation, prevailing soil types, and the occurrence of special soil features such as hardpan, this zone in Western Australia has been subdivided into 7 regions. Further subdivision is undoubtedly desirable and possible but is regarded as a problem requiring much greater detail than is possible in the present paper.

9.—CORRIGIN REGION: 5,400,000 ACRES.

The region lying immediately east of the Avon region of the red brown earth zone is called the Corrigin region. The average annual rainfall generally will fall into the 14 to 15 inch range. The main vegetation associations, which are present in any part of the region, include salmon gum, gimlet, morrel woodlands, mallee associations and sandy and gravelly heath. In addition, on the grey dune and related soils of the lake systems of the south—Lake Grace, Newdegate, Pingrup—a blackbutt (*Eucalyptus Kondininensis*), boree (*Melaleuca pauperiflora* and *M. quadrifaria*) association is characteristic.

The area is mapped as granitic but most of the parent materials of importance with respect to the principal agricultural soils are of the valley filling type, and possibly ancient sedimentary rocks.

The woodland and mallee soils are typically of greyish colour and form typically on the broad, flat valleys. Grey gimlet soils have long been recognised by farmers in the region and are representative of the heavier soil types. The sandy surfaced soils, with a clay subsoil within less than a foot of the surface, typically show evidence of solonetz structure and in many respects resemble solonetz soils described in other parts of Australia and of the world. Burvill and Teakle (1938) have recently discussed these soils more fully than is possible here.

In common with all other regions of this zone, lateritic sand and gravel heath country is typical of the higher levels. Much of this land has a clayey subsoil and resembles the soils described on the Esperance Plain (Teakle and Southern, 1936), and those observed on the Wongan Hills Research Station. Such soil types are proving valuable agricultural land in many

districts in the region when cropped at four or five year intervals. A judicious fodder and pasture establishment programme and stock raising are essential for the improvement of the soil fertility.

The Corrigin region is one of the most productive of the zone. The soils are less leached than further west and, in addition, the rainfall is more generous than further east. Cereals and sheep are the principal lines of production and improved pastures promise to stabilise the stocking programme. Dairying and pig raising are important adjuncts. The provision of more adequate water supplies, liberal use of superphosphate and better adapted pasture species will greatly increase the agricultural production of the area.

10.—MERREDIN REGION: 7,900,000 ACRES.

The central and eastern portions of the wheat belt of Western Australia are practically delineated by the Merredin region, which is typically an area of brown and red brown woodland soils, with intermediate patches of mallee country, and a considerable proportion of sandy and gravelly soils carrying heath and wodjil (*Acacia* spp.) plant associations. This region may be regarded as the most representative of the grey and brown calcareous, solonised soil zone and further description would be largely a repetition of information already discussed for the zone in general.

Of interest, and perhaps pedological significance, are siliceous hardpan soils which have formed on the extensive flats slightly above lake level in the Lake Brown valleys. These flats typically carry an acacia scrub, saltbush (*Atriplex, Rhagodia*), *Eremophila* spp., *Lycium australe,* etc., with scattered clumps of gimlet and yorrell (*Eucalyptus gracilis*). The soil profile is a red brown sand to sandy loam with a laminated, siliceous hardpan at a depth of about one foot. At one site, this hardpan layer was about one foot thick and was underlain by brownish red, acidic clay of high salinity.

It is worthy of note that the region falls naturally into at least two sub-regions. The northern arm along the Wongan Hills-Mullewa railway line is distinct topographically. It is more undulating and many of the hill formations are timbered by the typical eucalyptus woodlands, while the light sandy and gravelly heath and wodjil soils are commonly in the valleys. In the rest of the region the principal topographic features are the broad, flat valleys and the sandy and gravelly rises. In the valleys are the typical woodland soils and on the rises are the heath and wodjil associations which may be broken by patches of woodland and mallee where the sands and gravels have been removed.

The area is particularly important for cereal production and stock raising which is being facilitated by the provision of water from the Goldfields and local water schemes. The rainfall is low and somewhat uncertain in the north-eastern portion of the region, which is now being reorganised on a basis of stock production, but generally the rainfall is adequate in quantity and incidence for satisfactory wheat growing and stock raising.

11.—FITZGERALD REGION: 11,900,000 ACRES.

The Fitzgerald region occupies the southern portion of the zone and in common with the Corrigin region exhibits a considerable proportion of the greyer soil types. In the western portion of the region sand heath formations appear to occupy a larger proportion of the country than in any other

region of the zone. However, east of the Fitzgerald Peaks, gravelly and related soils are very much less extensive and clayey soils or sandy surfaced soils with clayey subsoils predominate.

Geologically, certain distinctive horizons have been observed, but, in many instances, the explanation is at present obscure. The presence of spicular sandstones probably of Miocene age has been established. A fragmental breccia or conglomerate is common in parts of the Salmon Gums area as a surface formation or has been found in the course of dam construction. Throughout the area a very tough and refractory siliceous rock, sometimes called siliceous "laterite," is very common.

The basal rocks appear to be granitic as in the bulk of the southern portion of the State. Low outcrops occur commonly throughout the region, and Peak Charles, about 20 miles west of Salmon Gums, is a bare granite boss rising to a height of 2,100 feet above sea level and 1,200 feet above the surrounding eucalyptus woodland. This peak rises 700 to 800 feet above the level of present lateritic horizons and probably represents a residual of an erosion cycle earlier than that culminating in the Great Plateau of Western Australia.

Basic dykes and segregations occur and in some districts metalliferous outcrops are the basis of mining activity: Ravensthorpe, Hatter Hill.

Another feature of the landscape is the salt lake, or salina, systems, which are very extensive west of the Fitzgerald Peaks and east of Salmon Gums.

Associated with the proximity to the Southern Ocean is a greater salt concentration in the heavier textured subsoils.

In addition to the ubiquitous salmon gum, gimlet and morrel woodlands and the heaths, certain special associations occur in this region. Probably the most important of these are the white barked redwood (*Eucalyptus oleosa* var. *transcontinentalis*), ribbon bark (*Euc. dumosa*) and merrit (*Euc. Flocktoniae*) woodlands and the considerable areas of stunted eucalypts and mallees such as *Euc. diptera, Euc. eremophila, Euc. annulata, Euc. Dielsii, Euc. spathulata, Euc. calycogona*, etc.

In many respects the soils resemble those of the Corrigin region but there are larger areas of the browner soil types particularly in the drier parts of the region. Perhaps the most characteristic soil type, however, is a grey to grey brown sand, often bleached in the subsurface layer, resting on a grey to olive brown calcareous, sandy clay subsoil which typically shows some development of solonetz structure. Examination of the woodland soils of the region shows them to be rich in potash, extremely poor in phosphate and to contain an undesirable quantity of salt. The effect of removing the timber on the movement of salt in this region has been discussed by Teakle and Burvill (1938) who show that the salt is rapidly leached from sandy surfaced soils after clearing.

The Fitzgerald region forms part of the undeveloped agricultural areas of the State. Development involves certain difficulties among which are the high proportion of sandy and gravelly heath country and the incidence of soil salinity. With the progress of agriculture in the State, this region will undoubtedly be utilised for cereal production and, more particularly, stock raising, but the areas of good woodland soils are too scattered for convenient land settlement.

12.—COOLGARDIE REGION: 23,000,000 ACRES.

The Coolgardie region lies immediately east of the agricultural areas and receives an annual rainfall averaging 10 to 11 inches.

The soil profile is characteristically of the solonised type with a calcareous subsoil but, under the low rainfall conditions, is less developed than in the more western regions. The surface is typically a red brown to brownish red sandy loam, sometimes a sandy clay loam, neutral to slightly alkaline in reaction, resting on a more or less massive sandy clay loam to sandy clay subsoil which contains several per cent. of calcium carbonate. Some concentration of salt is observed, particularly in the heavier soil types, and salinas often occupy the lowest portions of the valleys and depressions. Insufficient information is available for remarks concerning other chemical properties such as nitrogen, phosphate, potash, replaceable bases, etc.

ERRATA.

P. 157, line 15: For "*larvas*" read *lavas*.

P. 161, line 16: For "*Hakes*" read *Hakea*.

P. 175, line 8: For "*latcriate*" read *laterite*.

campaspe and a number of blackbutts (*Euc. Le Souefii, Euc. Dundasi*, etc.), as well as acacias, *Eremophilas*, saltbushes (*Atriplex* spp.) and sage bush (*Cratystylis conocephala*).

The soils are typically calcareous from a depth of 4 to 6 inches but the grey types, usually associated with morrel timber (*Euc. oleosa and Euc. melanoxylon*) and blackbutts, are calcareous from the surface. Blackish ferruginous gravel is of very common occurrence as a light surface pavement.

(2) Ancient sedimentary formations.

Sedimentary horizons, of which the Whitestone series (Forman, 1937) is a representative, appear to occur between the hill formations and are associated with reddish brown to brownish red soils which exhibit a "flat" surface appearance characteristic of low rainfall soils.

The subsoil is typically calcareous from a depth of 4 to 6 inches.

Gimlet (*Eucalyptus salubris*) is the most characteristic timber but salmon gum (*Euc. salmonophloia*), morrel (*Euc. oleosa*) and redwood (*Euc. oleosa* var. *transcontinentalis*) are important in the association.

The undergrowth consists largely of *Acacia* spp., *Eremophila* spp., saltbush, etc.

(3) Granitic outcrops.

The grantite outcrops, occurring as low hills and bosses, are generally associated with more immature and stony soils, lighter in texture and browner in colour. Calcareous accumulation in the subsoil is not characteristic except in heavier types. A more stunted vegetation grows on these types. Golden mallee (*Euc. foecunda*), jam (*Acacia acuminata*), kurrajong (*Sterculia Gregorii*), *Eremophila* spp., and some salmon gum (*Euc. salmonophloia*), and gimlet (*Euc. salubris*) are on the better soils and a heath, often largely tamma (*Casuarina campestris*), on the immature and skeletal types. Some grasses and herbs usually grow on these soils, rendering them of some grazing value in the virgin state.

(4) Lateritic and sandy formations.

Particularly on the western portion of the region and to the south large areas of high level heath country are associated with yellowish gravelly and sandy soils.

A wide variety of stunted shrubs and small trees grow on these soils and many produce a colourful display of flowers in the proper season.

Acacias, *Grevilleas, Hakeas, Actinostrobus, Thryptomene,* etc., are among the members of the plant association on these low fertility soils. The formation usually represents residual lateritic horizons, but in some cases other quartzose horizons are the parent material of the soil type which has developed.

Except on the western fringe, the soils of this region are not developed for agriculture on account of the deficient rainfall. Goldmining is the chief industry, but sheep and cattle raising are followed where saltbush and bluebush provide grazing and water supplies may be obtained.

13.—ZANTHUS REGION: 14,500,000 ACRES.

Abount 54 miles east of Kalgoorlie there is an apparent change in the appearance of the country. A somewhat similar change is noticeable at Fraser's Range some 66 miles east of Norseman. These points are taken as the western boundary of the Zanthus region.

In the Zanthus region greenstone intrusions, so characteristic in the Coolgardie region, are rare, and ironstone gravel or lateritic formations appear to be absent. Numerous salt lakes or salinas occur in the eastern part of the region.

The region is gently undulating and considerable portions are characterised by broad saltbush-bluebush-grass plains with scattered mulga and *Pittosporum,* interspersed with belts and patches of eucalyptus woodland and, in some cases, acacia and *Eremophila* scrubs. Kurrajong is fairly common, while spinifex enters the timber associations on the more sandy soils in the eastern part of the region.

In many instances, the timbers grow on the slightly higher country intersecting the plains. Salmon gum, morrel, redwood (*Euc. oleosa* var. *transcontinentalis*), gimlet, york gum mallee (*Euc. foecunda*), *Casuarina* and acacias (probably *A. microneura*) are the chief timbers, and there are three main types of undergrowth: (a) saltbush and bluebush—generally on the heavier and more calcareous soils; (b) acacia scrub, *Eremophila* spp., *Melaleuca* spp. —generally on the redder soil types—often heavy in texture; (c) spinifex—generally on the red sandy soil types. It has been observed that extensive developments of the saltbush-bluebush plains occur in the western part of the region along the Transcontinental railway and around Balladonia and eastwards (McLean, 1926). McLean also observed that sandplain country occurred south of Mt. Ragged which apparently fixes the south-western boundary of the region.

The soils show the principal characteristics of the zone. They range from red-brown and brown to grey in colour and show accumulation of calcium carbonate in the subsoil. Limestone rubble is common and, in the plain country, ridges of limestone are frequent occurrences. A certain amount of

pastoral development has taken place in this region but scanty water supplies are a drawback. Many of the soil types would be suitable for wheat production but the rainfall appears too low for agriculture.

14.—NINGHAN REGION: 7,600,000 ACRES.

The Ninghan region is really transitional between the red and brown acidic soils of the Yalgoo region and the main portion of the grey and brown calcareous, solonised soil zone. It is distinct from other regions in many respects.

The vegetation associations are principally eucalyptus woodlands and heaths but important areas of cypress-pine (*Callitris glauca*) and acacia scrub also occur. Unlike other regions, grasses and herbage grow in certain of the associations, particularly the york gum (*Eucalyptus foecunda* var. *loxophleba*) woodland.

The soils of the region are distinctly redder than in other parts of the zone and many types exhibit a surface "flatness" more characteristic of the red and brown acidic soil zone. Furthermore, a laminated, siliceous hardpan, commonly impregnated with calcium carbonate, is characteristic of the regional woodland, cypress-pine and acacia scrub soils. In addition to the normal salmon gum, gimlet and morrel woodland soil types, and the heath and wodjil soil types, representative profiles include—

(a) Red brown and red sandy loams with a "flat" surface and a laminated siliceous hardpan impregnated with calcium carbonate. These may be regarded as the characteristic woodland soils of the region and carry a woodland of york gum, jam (*Acacia acuminata*) and various scrubs. Grasses and herbage grow in the wet season.

It is interesting that this york gum is classified as the same species and variety (*Eucalyptus foecunda* var. *loxophleba*) as that of the red brown earth zone although its habit of growth is quite distinct.

(b) Salmon brown sandy soils of cypress-pine areas. These exhibit siliceous hardpan development, are acidic in reaction and generally low in plant foods. Simpson and Teakle (1934) have discussed these soils in some detail.

The occurrence of calcium carbonate in the hardpan, particularly as coatings between the laminae, suggests that the eucalyptus woodland association is encroaching on the acacia semi-desert scrub land and, concurrently, calcium carbonate is accumulating in the subsoils, *i.e.*, pedocals are being formed. It may be expected that the siliceous hardpan will slowly disintegrate in the alkaline medium and the profile improve agriculturally.

The agricultural value of the woodland soils of this region is somewhat lower generally than in regions where the hardpan is absent. However, successful cereal production and stock raising is practised throughout.

15.—HARTOGS REGION: 2,800,000 ACRES.

The extreme northern portion of this zone is at present outside the agricultural areas and has been mapped as the Hartogs region. A very considerable area of this region consists of heath often showing the form of sand dunes now fixed by the vegetation. The sand is a yellowish grey in colour in contrast with the red sands of the sand dunes in the Minilya region. Associated

with the sand heaths are areas of brown and red brown soils carrying eucalyptus woodland (principally york gum (*Euc. foecunda* var. *loxophleba*)), cypress-pine, mulga and mallee associations. G. H. Burvill (private communication) states that the mallee country of this region more closely resembles the drier portions of the Eastern States mallee than any other in Western Australia. He has observed that the heavier textured red brown soils of the flats carried stunted york gum, acacia scrub, *Eremophila* spp. while on the intervening red brown sandy rises mallee (including *Euc. oleosa*) and scrub predominated. The subsoils of these types generally appeared to be calcareous and in some portions a limestone pavement was very apparent. In certain areas mulga, cypress-pine and mallee grew on red brown soil types.

D. THE ZONE OF RED AND BROWN ACIDIC SOILS OF THE ACACIA SEMI-DESERT SCRUB—204,000,000 acres.

Between the north and south 10 inch isohyets lies a belt of red and brown soils, generally more or less acidic in reaction, and characterised by an acacia scrub, ranging from 10 to 20 feet in height, which is collectively described as mulga.

The western portion of the zone consists of Cainozoic, Cretaceous and Permian deposits with more or less horizontal bedding. East of these, the rocks are Pre-Cambrian; in the north, the Nullagine and Mosquito Creek Series (mainly sediments, lava flows and some granites) occur, and in the south, granites with small, but important, intrusions of greenstones, predominate.

Physiographically, the area is portion of the Great Plateau, now eroded to broad, flat, featureless valleys on the east and, in the west, to a more dissected and hilly topography. Except in the coastal areas the elevation generally ranges from 1,000 to 2,000 feet above sea level. The residuals of the Great Plateau now appear as low hills, ridges, and quite imposing ranges rising abruptly out of the plain or "new" plateau, and are frequently capped with laterite.

In the eastern portion of the zone spinifex covered sandhill formations occur, particularly on certain sedimentary rocks, and small saltbush and bluebush steppes are important features from the pastoral viewpoint.

The bulk of the area (west of 120° E. lat.) is drained by a number of intermittent streams running into the west coast; the Murchison, Wooramel, Gascoyne and Ashburton being the chief rivers. East of this the drainage is endoreic, i.e., into depressions and "lakes," or salinas, of the interior. The Savory Creek at Mundiwindi and such "lakes" as Lake Carey and Lake Carnegie are examples of this interior drainage system.

The drainage of this low rainfall zone contrasts with that of the more southern zone of grey and brown solonised soils where the rainfall is higher, but the precipitation per wet day is considerably lower, and where no "rivers" ever flow to the sea.

The climate is definitely arid. The rainfall is generally below 10 inches per annum and according to Barkley (1931) the coefficient of variation ranges from 30 to 60 per cent. Evaporation is high and ranges from about 7½ feet in the south to nearly 15 feet per annum at Mundiwindi. In no month of the year does the average rainfall exceed the evaporation. If a monthly precipitation: saturation deficit ratio of 7.5 be taken to indicate the minimum

moisture conditions for continuous plant growth, only in June will the conditions in the bulk of this zone approach or exceed this figure. On the coast, at Carnarvon, this ratio is exceeded during June and July and at Yalgoo, near the boundary of the grey and brown calcareous, solonised soil zone east of Geraldton, during May, June, July and August (Teakle (1936) p. 497). However, much of the useful rain of this zone comes in heavy falls, which are valuable for the xerophytic and ephemeral plants in whatever season of the year they occur.

The vegetation of the zone is predominantly mulga. Botanically, mulga is *Acacia aneura* but the term may conveniently be extended to include a number of associated species of *Acacia,* generally ranging from 10 to 20 feet tall, including bowgada bush (*A. linophylla*), *A. Burkittii,* curara (*A. genistoides*), minerichi (*A. Grasbyi*), snake bush (*A. eremaea*), gidgee (*Acacia* sp.), etc.

A wide variety of shrubs and bushes grow with the acacias. Examples are beefwood (*Hakes* sp.), cork (*H. subera*), turpentine bush (*Eremophila Fraseri*), poplar (*Plectronia latifolia*), flannel bush (*Solanum ellipticum*), poverty bush (*Acacia leptopetala*), starvation bush (*Eremophila Youngii*) and emu bush (*Eremophila longifolia*). Eucalypts and other trees generally fringe the creeks and grow in the river valleys. River gum (*Eucalyptus rostrata*), coolibah (*Euc. microtheca*) and *Casuarina lepidophloia* are commonest representatives. *Eucalyptus longicornis* and desert gum (*Euc. eudesmoides*) are fairly common in certain areas.

With the shrubs and timbers are a wide variety of ephemeral herbs, particularly *Compositeae,* in the southern portion of winter rainfall, and perennial grasses in the northern areas where summer rainfall predominates.

Spinifex occurs in patches and saltbush and bluebush are common, particularly in the east.

The soils fall into two main groups—

(a) Those of the central and southern areas in which a well defined hardpan has developed on the broad plains.

(b) Those of the northern and western portions where the topography is more hilly and the hardpan is absent or only intermittently developed.

In the surface features the soils generally are similar, being shades of red and brown in colour, more or less sandy in texture and non-calcareous. The profile generally shows little differentiation except where the hardpan occurs. The subsoil may be recognised by slight clay accumulation, concentration of pebbles and small stones and a brighter colour. Serir* formation is typical: the commonest stones of the pavement are white quartz and dark red brown quartz-haematite.

Chemically, the soils are not rich in plant foods, are very low in water soluble salts, and calcium and magnesium predominate in the replaceable base fraction. In the hardpan soils the content of replaceable bases is very low, ranging from 10 to 30 m. eq. per 100 gm. of clay and the

*The term "serir" has been adopted in soil nomenclature for those desertic soils which are characterised by a stony surface or "desert pavement." It is of Arab origin. Such formations are commonly called "gibber" plains in Australia.

TABLE 11.

Distribution table showing the reactions of Soil samples from sites in the zone of red and brown acidic soils of the acacia semi-desert scrub.

—	Number of Samples in each Range.										Total Number of Samples.
Range, pH	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	
A.—Sites other than Carnarvon terrace soils.*											
Surface	6	5	1	4	7	5	6	2	6†	5†	47
Subsoil	2	3	1	1	4	5	2	...	1	2	21
B.—Sites from the Carnarvon terrace soils.‡ (Teakle & Southern, 1935.)											
Surface	...	...	...	...	...	...	2	2	7	1	12
Subsoil	...	...	...	...	...	...	2	2	3	4	11

* Includes samples A1193–1217, 1879–1902, 1833–1853, 2549–2567. † Includes one sample from a garden in which the soil has apparently been rendered alkaline by the treatment. ‡ Includes samples A1156–1192.

clay appears to be of the nontronite type. Also, they are typically acidic in reaction with a pH value of 5 to 7. (See Table 11.) More alkaline soils are generally associated with lacustrine formations or patches of calcium carbonate accumulation.

The nature and occurrence of the hardpan has already been discussed (Teakle, 1936). It appears as a laminated subsoil cemented by silica and generally coloured by oxides of iron. The surface soil usually ranges from six inches to 36 inches deep and rests abruptly on this very hard layer commonly known locally as cement. The hardpan occurs as laminae about one inch thick, is generally non-calcareous in the upper layers and may be many feet thick. Calcium carbonate is frequently observed with depth as small lenses between the laminae and sometimes as a surface coating on the otherwise non-calcareous layers. Melville (private communication) has observed calcium carbnate accumulation at a depth of about 10 feet and immediately above the country rock at Boolardy Station. Unconsolidated river deposits are reported to lie below the hardpan in some instances.

The ferruginous colouring may be readily removed by digestion with hydrochloric acid, which leaves a white sandstone. Hydrofluoric acid attacks the siliceous cement and disintegrates the hardpan. Instances have been observed in the field in which the hardpan is whitish and not coloured by iron oxides.

It has been observed in other instances in Western Australia and also by Taylor and England (1929) in the Eastern States that siliceous cementation is liable to occur where occasional floodings take place. As the soils of the hardpan zone are liable to periodic floodings following the occasional very heavy rains, it is thought that this condition, under a slightly acidic reaction, is responsible for the solution of silica which is subsequently deposited as a cement in the subsoil on drying out.

Jutson has explained the formation of the broad, featureless valleys of the hardpan zone as the result of wide lateral erosion with restricted vertical corrasion. In these valleys, drainage of the soils is apparently largely lateral and calcium carbonate moves out in solution to be deposited in "opaline"* patches and in broad lacustrine formations. Where the calcium carbonate is deposited, it is usual to find salt bush and blue bush predominating in the vegetation association.

Where sand formations occur, usually obviously aeolian formations, spinifex is the most characteristic element of the vegetation.

The acacia semi-desert zone is subdivided into regions on the basis of soil, topographic and vegetation features.

Group A.—Regions of Hardpan soils.

16.—MURCHISON REGION: 43,800,000 ACRES.

The Murchison Region presents the most typical occurrence of the red hardpan soils. It is a high level plateau characterised by broad, featureless plains of red serir soils with a hardpan generally within a foot of the surface. The plains are broken by various types of residual hills. It is typically a mulga formation but the mulga is much more sparse than further south. North of the Robinson Range (Peak Hill) perennial grasses are im-

*Patches of calcium carbonate accumulation, usually in the form of white nodules, are designated as "opaline" patches in popular parlance. True opal does not occur but flints have been observed in one instance.

portant pastorally, but to the south, where winter rains predominate, ephemeral herbage constitutes the principal ground vegetation—and then only after rains. This southern area is largely granitic with important outcrops of greenstone. The northern portion is predominantly of the Nullagine and Mosquito Creek series.

Some five groups of soil have been recognised—

(a) Mulga bush plains—brownish red sand to sandy clay loam with the hardpan at 6 to 12 inches deep. The soils are generally gravelly and show the serir surface but areas of stoneless soils may be observed. Where the reddish sand has accumulated in depressions or on low ridges, the hardpan is at a greater depth. These areas are known as wandarrie soils and are most suitable for homestead gardens.

(b) Channel country—heavier textured soils and "opaline," or calcareous patches are associated with the broad river channels. The river channels themselves are brown sands and grits.

The vegetation reflects the wetter conditions and includes curara, wattles, mulga, eucalyptus, *Casuarina lepidophloia*, grasses (*Aristida* spp.), *Eragrostis* spp., and kangaroo grass (*Themeda triandra*). Native vetches (*Swainsona* spp.) and native lucerne (*Trigonella suavissima*) flourish after periods of flooding. The association is a woodland or savannah woodland.

(c) Undulating granitic country where granites are exposed at shallow depths—a brownish red immature soil with decomposing granite in the subsoil and an abundance of granitic boulders and outcrops is observed. The vegetation resembles that of the mulga bush plains.

On Murramunda Station near Mundiwindi a similar formation of brown soils occurs. The typical vegetation associations are mulga and grass, and mulga, grass and spinifex.

(d) Lacustrine formations and calcareous soils—brown, pinkish brown to pinkish red calcareous soils with calcareous rubble in the subsoil occur in relatively small patches throughout the region. Mulga and grasses may grow on these soils but more generally the vegetation includes saltbush and bluebush and sometimes samphire with or without mulga. These areas are very valuable pastorally as the edible vegetation is within reach of the sheep.

(e) Stony and gravelly hill formations carrying (i) mulga bush, (ii) spinifex associations. Laterite frequently occurs on these formations.

17.—YALGOO REGION: 19,100,000 ACRES.

South of the Murchison region, and bordering the grey and brown solonised soils of the eucalyptus woodland the country is more undulating, the granites are exposed more frequently, considerable areas of browner soils are observed, there is evidence of a more general occurrence of laterite in patches, and the vegetation shows many typical features. The elevation is lower and ranges from about 1,000 feet to 1,400 feet above sea level.

Geologically, the area is mapped as predominantly granitic and on the granitic exposures the soil is commonly a red brown, coarse, loamy sand resting on decomposing rock. Laterite is common and lateritic gravelly soils, usually yellow brown in colour, occur where the gravels have been broken in the course of erosion. Some of these gravelly soils exhibit a peculiar physical condition in that the surface sand lacks coherence.

The vegetation is predominantly of the acacia scrub type and some patches of dense, tall, well grown mulga may be observed. However, cypress-pine (*Callitris glauca*) is common and forms a woodland in patches on the western and southern parts of the region. *Eucalyptus oleosa*, as a mallee, is common in patches, york gum (*Euc. foecunda* var., *loxophleba*) occurs in many places and jam (probably *Acacia acuminata*) is to be observed in many of the associations. Kurrajong (*Sterculia Gregorii*) grows more commonly as scattered trees in the inner portions of the region.

The soils of the flat areas, which may be taken to represent the zone, are typically of the serir type, are usually brown, red brown and brownish red in colour, sandy loam in texture and typically show the hardpan at shallow depths. While the hardpan is usually red brown in colour with black markings, outcrops of a brittle, light buff coloured type have been observed. In the hills much stony surfaced country exists. Sandy areas typically carry spinifex and scattered gums.

East of Mt. Magnet, more bluebush (*Kochia*) and salt bush (*Atriplex*) are seen with the mulga, on "opaline" patches, and on patches of open plain. These open bluebush and saltbush flats are often highly calcareous and flints are found in some of the limestone formations.

Running southwards from Paynesville on the Sandstone railway line, is a strip of red crumbly clay country carrying saltbush and bluebush. This strip is 10 to 40 chains wide and reaches the rabbit proof fence about 100 miles south of the railway line. It is probably related to some special geological feature and shows affinities with the brown soil group of the Kimberleys and the Fortescue Sunkland, rather than with the other soils of this region.

The soils of the cypress-pine associations have been described and discussed by Simpson and Teakle (1934). It appears that these soils are generally red brown in colour (usually a salmon tinge is noticeable in the field), loamy sand to sandy loam in texture and acidic in reaction. They are relatively low in the usual plant foods, very low in water soluble salts, and in the lower lying portions show a siliceous hardpan in the second foot layer.

18.—BARLEE REGION: 44,100,000 ACRES.

East of the Yalgoo and Murchison regions, salt lake formations and saltbush flats become very important soil and pastoral features and are associated with spinifex plains and sandhills, and mulga country. It is estimated that each of these three formations occupies approximately the same proportion of the region.

Talbot (1928) has observed that the reddish soils of the sandy plains, carrying spinifex, desert gum and bloodwood, are forming on granitic rocks, while the sandhills form where the rocks are sedimentary. Possibly the shape of the sand grains is an important factor in conditioning this difference in topography under a similar vegetation association. In the north-western portion of the area, he has reported that the Mosquito Creek series is characterised by mulga flats and red soils, while sandhills have formed on rocks of the Nullagine series.

The mulga scrub, often very dense, generally appears to be associated with reddish soils resembling those of the Murchison region. Serir soils are common, red sandy soils are developed extensively under a mulga-spinifex

association, and mulga and saltbush often associate on the richer flats. Hard, red soils, with a cover of mulga, occur on diorite outcrops. Hardpan appears to have developed generally in these "mulga" soils.

In May, 1938, through the courtesy of Miss N. Burbidge, of the University of Western Australia, a number of soil samples were obtained from Glenorn Station, Malcolm. These represented various vegetation associations studied in the field and show that the soils range from brown to red brown in colour and from sands to sandy clays in texture. Certain types are alkaline in reaction and some of these are calcareous but other soils are slightly acidic. Hardpan was present in most types examined at depths ranging from 4 inches to over 4 feet but was generally encountered between 6 and 18 inches deep. Some of the lowlying soils and soils from claypans and lakes were distinctly saline but the "normal" soils were very low in soluble matter. Information available is summarised in Tables 12 and 13.

TABLE 12.

Analyses of Soil Samples from Glenorn Station, Malcolm, Barlee region. Collected May, 1938, by Miss N. Burbidge, University of W.A.

Serial No.	Depth.	pH.*	Lime ($CaCO_3$).	Spec. Resist. ohms at 60° F. (1 : 5 water suspension).	Salt (NaCl).
	inches.				%
2549	0—6	8·50	rich	1,410	0·15
2550	0—6	8·32	nil	730	0·36
2551	0—6	8·47	nil	13,700	0·008
2552	0—6	8·24	present	550	0·36
2553	at 36	8·74	rich	432	0·63
2554	0—6	7·26	nil	29,700	0·005
2555	0—6	6·46**	nil	41,000	0·005
2556	0—6	5·60	nil	15,500	0·003
2557	at 18	6·46	nil	38,700	0·005
2558	0—6	6·50	nil	32,000	0·003
2559	0—6	7·38	nil	238	1·33
2560	0—6	8·27	rich	2,880	0·07
2561	0—6	6·85	nil	500	0·61
2562	0—6	7·32	nil	16,850	0·01
2563	0—6	6·59	nil	730	0·38
2564	0—6	8·54	nil	1,250	0·22
2565	0—6	6·84	nil	22,300	0·008
2566	0—6	8·23	nil	1,190	0·16
2567	0—6	6·31	nil	21,800	0·008

*Quinhydrone electrode—1 : 5 suspension. Rapid positive drift (to higher pH) occurred with most samples. Reading after 10 seconds adopted.

**Glass electrode.

The extensive saltbush and bluebush flats are generally associated with pinkish and brownish calcareous soils and are of considerable importance pastorally as the edible forage is readily available to the stock. In combination with the mulga and spinifex areas a very stable grazing unit is established but is liable to damage by overstocking.

TABLE 13.

Distribution table showing the reaction of surface Soil Samples and the depth of the hardpan at certain sites on Glenorn Station, Malcolm

—	Number of Samples in each Range.							
Range. pH	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8
	1	1	3	2	3		4*	3*
Range of Depths of Hardpan (inches)	0—6	6—12	12—18	18—24	24—30	30—36	36—48	deeper than 48
	3	31	21	9	14	7	4	7

* Includes one sample from a garden in which the soil has apparently been rendered alkaline by the treatment.

19.—WARBURTON REGION: 57,000,000 ACRES.

The area of transitional country between the zone of typical "mulga" country and the main central sandhill region (the Carnegie region) has been included in the Warburton region. Two main formations characterise this area:

(a) The sandhill and sand plain country carrying a cover of spinifex and desert mallees.

(b) Areas carrying mulga and associated scrubs on flats between the sandhills and on the country associated with the ranges.

Talbot (1928), Talbot and Clarke (1917), and Forman (private communication) have made observations in this area. On their expedition from Laverton via the Townshend Range to the South Australian border, Talbot and Clarke mention the mulga, spinifex and saltbush country in the vicinity of Laverton (Barlee region), but describe the rest of the traverse to the Townshend Range as largely red sandy plains and red sandhills carrying spinifex and desert mallees and gums. The sandhills range from 200 yards to a mile apart and average about 30 feet high. Breakaways and stony rises (probably of the Cretaceous Wilkinson Range series) occur and usually carry a vegetation cover of spinifex probably resembling the Ophthalmia Range in this respect. Red sandy and loamy soils, which become very boggy when wet, are associated with these rises and usually carry mulga, desert gums, etc., with wandarrie and wind grasses (*Aristida* spp.). Forman (private communication) has observed that hardpan is characteristic of the soils of the mulga flats of the region.

In the Warburton Range area is about a million acres of quite good pastoral country of the mulga type. The red soil flats carry mulga and spinifex and the sandy soils mulga, wandarrie and wind grasses. Saltbush occurs on some flats and appears to be prevalent south-west of the range. Mr. Forman has observed that the heaviest mulga is associated with the sediments and volcanics of the Nullagine series and the quartzites carry spinifex and odd fig trees (*Ficus* sp.).

The western portion of the region comprises extensive areas of red sandhills carrying spinifex and also plain country carrying mulga and other scrubs, between the ranges and hills. South of Lake Carnegie are extensive saltbush plains and samphire flats with scattered mulga.

The Warburton region is generally of low pastoral value but patches of good country exist and are being developed for sheep where distances from established centres are not too great. Some of the best grazing land

is in the Warburton Range area is isolated from Laverton by 300 miles of very poor and inhospitable country. Successful and well-known stations occur in the more western sections of the region (for example, Wongawol Station on Lake Carnegie).

The Warburton region of Clarke (1926) is restricted to the range country of the eastern portion of this region.

Group B.—Regions without general development of hardpan.

20.—GASCOYNE REGION: 13,500,000 ACRES.

The region includes the bulk of the Permian deposits east of the Minilya region as well as Nullagine and granitic rocks and is characteristically hilly and very stony. Serir formation is most marked and the soils, generally brown to red brown sandy loams to loams, are deeper and more immature than in the Murchison country further inland. Some cementation in the subsoil is common and the hardpan is observed in some places. Limestones are often associated with heavier textured soils. The only soil examined for this region (A1196) was a soil with exceptionally high content of replaceable bases (230 m. eq. per 100 gm. clay) and peculiar colloidal properties. The fine sand fraction contained beidellite instead of the more common nontronite and the reaction was slightly alkaline.

The general vegetation is similar to other parts of the zone but a larger proportion of perennial grasses in many parts allows a heavier stocking programme to be followed.

Laterite is observed in the region, *e.g.*, at the Wooramel crossing.

21.—MINILYA REGION: 7,400,000 ACRES.

Along the west coast, on sediments ranging from Cretaceous to recent in age, occurs a strip of country much of which is characterised by parallel sandhill formations 10 to 30 feet high, running generally northerly and southerly in direction, and fixed by acacia scrubs such as bowgada bush.

The soil of the sandhills is brownish red sand with no profile development. Between the sandhills are flats of higher fertility which carry mulga, wattle (*Acacia sp.*), *Hakea* spp., with a variety of grasses and herbage following rains. The soil of the flats is a brownish red sandy loam with clay accumulation in the subsoil. Cementation is observed in some instances but is uncommon, probably on account of the immaturity of the soils. A shallow claypan usually occupies the lowest portion of the flat.

Coastal formations include a variety of sandhills carrying shrubs, wattles, halophytes, etc., quite distinct from the more inland types.

Along the rivers recent alluvial soils, of a relatively high fertility level, have been deposited in terraces and, where irrigation is possible, are valuable for tropical agriculture (Teakle & Southern, 1935). In contrast with the normal soils of the zone, these soils are alkaline (Table 11).

The Minilya region corresponds generally to Clarke's (1926) Carnarvon natural region. It joins the spinifex steppe formations on the north, and the yellowish and greyish sand heath formations in the "mallee" zone on the south. Forman (private communication) considers that this break from red to yellowish and greyish sandy soils at the Minilya-Hartogs boundary is probably due to the exposure of a calcareous bed of the Cretaceous series

in the Hartogs region in contrast with argillaceous beds in the Minilya region. The hilly formations to the east are separated and included in the Gascoyne region.

22.—ASHBURTON REGION: 19,100,000 ACRES.

The upper courses of the Ashburton and Fortescue rivers drain the northern portion of the mulga zone and the southern portion of the desert steppe zone of the North-West. The area may be regarded as a dissected plateau averaging 2,500 to 2,750 feet above sea-level. Mt. Bruce (4,024 feet), the highest point in Western Australia, lies in the region. The dissection has resulted in the formation of rough, stony hills and ranges which are covered with spinifex and small trees and shrubs such an kanji (*Acacia pyrifolia*). Between the ranges are valleys, the heavy textured soils of the bottoms of which are of the brown type, similar to the soils of the tropical savannahs, etc., of zone H. Likewise these soils carry a savannah or grassland vegetation association. The lower slopes typically carry a mulga association, but hardpan as a feature of these soils has not been reported.

The region is regarded as transitional between the semi-desert steppe zone to the north and the mulga zone to the south.

The eastern portion of the region includes the Fortescue sunkland represented by the Roy Hill and Ethel Creek Stations. In this portion, the valley and plain soils observed fall into four groups.

(a) Brown clay soils of the Fortescue savannah and other grasslands. The profile is a brown clay loam or clay on a hard clay subsoil. Cracking during dry weather is characteristic. Patches of calcium carbonate accumulation are common and here the soil has a crumbly structure.

Inundation during wet periods and the heavy texture give the soil the equivalent of a higher rainfall. Consequently, the vegetation and soil are more representative of higher rainfall areas such as the Fitzroy of the Kimberleys, and Queensland. A Mitchell grass (*Astrebla pectinata*) savannah is a prominent feature. A variety of other grasses occurs, and the scattered trees include coolibah (*Eucalyptus microtheca*) and sugar gum (*Euc. sp.*).

(b) Reddish brown to brownish red sandy loams to sandy clay loams on a sandy clay subsoil, apparently forming on material of alluvial origin as well as on higher level country. Hardpan was not observed.

The vegetation includes mulga, eucalypts, *Hakea lorea, Cassia notabilis* and spp., as well as grasses and spinifex.

(c) Sandy and serir plains of the valley which carry spinifex and scattered coolibah and river gum. Wind erosion has caused severe damage on some of this country.

(d) Brownish red heavy clays of basaltic plains. Mulga and grass grow on these soils.

Geologically, the region is principally of the Nullagine and Mosquito Creek Series. Laterite commonly occurs as a capping of the hills.

Cattle and sheep are grazed in this region but the difficulties of marketing are promoting a swing towards sheep.

Grasses of the grassland and savannah formations, and associated with the acacia scrub (mulga) are of great importance and a representative variety from Turee Creek Station has been examined seasonally by Beck and Underwood (1938) for chemical properties.

E.—THE ZONE OF BROWN ACIDIC SOILS OF THE SEMI-DESERT STEPPES OF THE NORTH WEST—36,600,000 ACRES.

The northern portion of the north west is characterised by "spinifex" or porcupine grass country (*Triodia* spp., etc.) and may be described as a semi-desert steppe formation. Scattered bushes and small trees grow and the better rainfall areas in the proximity of the coast could probably be described as a semi-desert savannah. Little is known of the soils except that they are generally brown to red brown in colour, sandy to sandy loam in texture, generally non-calcareous, slightly acidic, and without marked profile development.

The reactions of representative soils of this zone are indicated by the following distribution table:—

—	Number of samples in each range.									
Range, pH	5·2—5·6	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8	above 8·8
Surface ...	1	....	4	2	2	....	....	1	1	....
Subsoil...	....	...	1	3	1	....	....	....	....	1

It is considered that the area represents one of relatively immature soils of the leached group. A leached group of soils in a tropical region where the average rainfall is only 10 to 15 inches per annum may seem a paradox but it must be remembered that a considerable proportion of the precipitation falls in heavy deluges so that the climate temporarily is highly humid and consequently the soils exhibit the characteristics of leached soils.

At least four formations or regions may be recognised in the zone:—

(1) *Nullagine region*: rough range country where spinifex grows alike on the restricted sandy plains and on the rough, skeletal soils of the gravelly and stony hills.

(2) *Warralong region*: rolling spinifex plains where the soils are generally brown and red brown sands and sandy loams.

(3) *Hamersley region*: rough range and tableland country carrying spinifex on the skeletal soils of the hills and with areas of grassland, largely *Eragrostis* spp., on the brown clayey soils of the fertile plains.

(4) *Lyndon region*: undulating spinifex grasslands.

This zone corresponds rather closely with Clarke's (1926) "North West Region."

The climate is similar throughout. The rainfall ranges from 10 to 15 inches per annum, the summer temperatures are notoriously high (Marble Bar is one of the hottest places in the world), and for no month does the average precipitation exceed the evaporation. Exceptionally heavy rains associated with the summer hurricane season are of not infrequent occurrence as exampled by the records of Whim Creek for 24 hour periods:

3rd April, 1898	29.41 inches.
21st March, 1899	18.17 „
6th March, 1900	10.03 „
3rd March, 1903	10.44 „

23.—THE NULLAGINE REGION: 13,300,000 ACRES.

Mulga, as a feature of the landscape, disappears in the range formation north of the Fortescue sunkland and its place is taken by spinifex (*Triodia* spp. and *Triraphis* spp.) steppes with scattered small trees including kanji (*Acacia pyrifolia*), bloodwood (*Euc. lamprocarpa*), *Grevillea pyramidalis*, cork (*Hakea lorea*), etc. Coolibah (*Euc. microtheca*), minerichi (*Acacia Grasbyi*), various grasses, *Cassia* spp., etc., are common in the alluvial areas.

The region has the appearance of a dissected plateau of Nullagine Series, Mosquito Creek Series and intervening granites and is of very rugged and immature topography, particularly in the south. Toward the north, in the vicinity of Marble Bar, there is more high level plain country generally associated with granites dissected by diorite reefs. The scenery is typically rugged: rough hills of dark reddish brown colour, covered with sparse spinifex and scattered scrub. The numerous creeks, where soil conditions are better, are usually associated with a growth of small trees, shrubs and grasses.

While the area is predominantly one of brown to red brown skeletal soils, considerable occurrences of stony surfaced, or serir, soils are noted in the region.

Stony fragments are most commonly of resistant quartz or ferruginous quartzite. Underneath the stony layer is a brownish sandy textured soil with little evidence of profile development. Where the soil is very sandy, serir does not develop and a loose formation, liable to drift under the action of wind, is encountered. On the more productive plains in the north, *e.g.*, Talga Talga and Eginbar, the stony surface or desert pavement is less marked.

Characteristic soil types, which may be considered as intrazonal, develop on the more basic rocks. Outcrops of basalts usually give rise to a brownish red crumbly clay: other basic rocks frequently form a dark grey carbonated soil with magnesite boulders. Patches of calcareous, or opaline, soils occur in the valleys apparently as a result of the precipitation of calcium carbonate as spring waters are warmed by exposure to surface conditions.

Laterite is observed on many of the flat topped hills. Special mention may be made of the ferruginous laterite above a shaly sandstone on Telegraph Hill at Nullagine township.

An interesting characteristic of many of the valleys and plains are huge ant-hills 6 to 8 feet high and pyramidal or conical in shape. In harmony with the rough hills, they are dark red brown in colour.

The Nullagine region is developed for Merino sheep in the more favoured areas. By burning the spinifex on the hills at intervals, a more or less satisfactory growth of herbage may be maintained and much new country is being utilised by this device. A disorder, known as "staggers," develops among sheep on spinifex in this region. Control is apparently effected by feeding salt licks.

24.—THE WARRALONG REGION: 6,800,000 ACRES.

Immediately north of Eginbar Homestead the vegetation changes. The trees grow larger and taller (15 to 20 feet) and white wood (*Atalaya hemiglauca*) and warralong or camel tree (*Bauhinia Cunninghamii*) join the association. Experience shows that the spinifex generally is of better feeding value and much is of the "soft" type more highly prized by stockmen. Other

grasses, herbs, succulents and shrubs assume a more important place in the associations. The formation generally may be described as a semi-desert savannah.

Along the rivers large eucalypts occur in a woodland formation.

Physiographically the region is gently undulating and slopes from the foot of the tableland country to the coast on the north. Outcrops of rough stony hills occur and serve to break the monotony of the plain. An example is the Ord Range near Port Hedland.

Granite is the principal inland geological formation.

Three main groups of soils have been observed:—

(a) Brown to red brown gritty sands and sandy loams with or without a clay accumulation in the subsoil. Some tendency to cementation in the subsoil may be noted. Serir formation occurs but is not as usual as on more southern regions. Patches of heavier soils occur, as also do looser sands, in restricted areas. The better and more productive soils occur along the small streams and valleys.

The chief elements of the vegetation are spinifex (*Triodia* spp., *Triraphis* spp.), wire grass (*Eragrostis* sp.), weeping grass (*Chrysopogon Gryllus*), various other grasses and shrubs (particularly along creeks), *Bauhinia Cunninghamii, Atalaya hemiglauca*, and the ubiquitous kanji (*Acacia pyrifolia*). In various patches, more particularly where the soil is lighter in texture, other acacias are observed (*A. retinervis, A. holsericea*), minerichi, also native walnut (*Owenia reticulata*), *Melaleuca lasiandra, Grevillea leucadendron* and *Hakea lorea* usually as a savannah formation. Eucalypts occur in patches, particularly along creeks where the soil conditions are better.

Where the vegetation has been destroyed some damage from wind action occurs and leads to the formation of "clay pans."

(b) Flats associated with the rivers and littoral or flood plain formations.

Brown and red brown sands, loams and clays, carrying both woodland and grassland or shrub associations, occur along the rivers and along the coast. With traffic, in some patches the soil becomes powdery and liable to wind erosion. Also there are considerable areas of wind eroded country where the vegetation has been destroyed. These patches are commonly known as "claypans" and often show a stony pavement surface. Herbage is difficult to establish on them unless the surface is broken by means of an implement.

In the coastal areas, salt water at shallow depths is frequently encountered and presents a problem in the provision of stock water.

A much wider variety of vegetation grows in these areas so much better favoured for moisture. A woodland association characterises the river banks, eucalypts predominating. Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), Buffel grass (*Pennisetum cenchroides*) and weeping grass (*Chrysopogon Gryllus*), as well as spinifex, represent the grasses, and in the treeless country *Atriplex, Bassia divaricata,* samphire (*Salicornia* sp.) and "lucerne" (*Trigonella suavissima*) are important. The "lucerne" is used for hay purposes.

(c) Coastal sandhills and mangrove flats.

These formations are observed along the coast. Owing to the high tides —up to 25 feet—lower lying areas, subject to flooding by tidal waters, are

mud flats carrying mangroves. The sandhills are similar to those elsewhere along the coast.

In his ecological studies in the region, Anderson (private communication) found that the association of small trees gave the best indication of the grazing value of the country. Thus, the edible *Bauhinia Cunninghamii* and *Atalaya hemiglauca* are associated with the better classes of country, and the inedible *Acacia* spp., *Owenia reticulata* and *Grevillea leucadendron* with the less valuable areas where the soil is more sandy. The species of spinifex occurring in both associations are practically the same. The feeding value of the various types of edible spinifex was dependent on the nature or fertility of the soil type on which it was growing, rather than on the species. Any of the types of "soft" spinifex may be found growing in either association but other perennial grasses and annuals are mostly confined to the better classes of country.

25.—THE HAMERSLEY REGION: 10,600,000 ACRES.

The dissected tableland between the Ashburton River and the Warralong region has been included in the Hamersley region.

This area consists principally of rough ranges with skeletal soils of the brown group, and the undulating, grassy, brown soil plains of the coastal areas.

These coastal areas are known as the Roebourne Plains. The soils of the grasslands are generally clayey in texture but areas of lighter loams occur associated with spinifex, and rough spinifex covered hills bound the plain. Along the creeks and rivers belts of eucalypts and acacias have established. Stunted kanji and gema bush grow on some sites in the grassland.

The tableland and range country is covered with spinifex, kanji (*Acacia pyrifolia*) and snakewood (*Acacia eremaea*) growing in very stony shallow, brown soil. From Millstream southwards eucalypts appear to replace the kanji. In the valleys, rich flats of brown clayey soils have formed. These are typically grassland soils and carry *Eragrostis* spp., Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), etc. With the grasses are patches of kanji, snakewood, gema bush and wattle.

South of Mt. Florance belts of mulga occur on the lower slopes and grasses in the valleys. This section obviously falls in the transitional Ashburton region.

26.—LYNDON REGION: 5,900,000 ACRES.

G. F. Melville (private communication) has suggested that the country between the Lyndon River and Peedamullah Station may be appropriately mapped as a region of the brown acidic soils of the semi-desert steppes. This area is probably one of the best grazing regions of the pastoral areas and consists largely of red and red brown sandy soils of the spinifex plains, restricted areas of rough stony soils of the rises and hills, and brown clay soils of the Ashburton flood plain and other rivers.

The spinifex plains are sandy, more or less undulating, and carry either a pure spinifex stand or spinifex associated with kanji and snakebush. Ephemerals such as *Trichinium* spp., grasses and other plants grow with the spinifex. Where claypans occur, open grassland and patches of acacia scrub occur. Lines of consolidated sandhills are observed in some parts.

The rough, stony hills carry spinifex and scrubby acacias including snakebush and kanji. The soils are of the skeletal group.

Along the Ashburton and other rivers are extensive plains. These are usually open grassy flats of brown clayey soils and are broken by scattered clumps of curara, snakewood and other acacias. Flood gums (*Eucalyptus rostrata*) grow along the channels.

The western coastal areas are largely spinifex covered, red sandy soils —either gently undulating plains or low sandhills—with patches of heavier stony country and limestone outcrops. For a width of a few miles along the coast grey sandy soils occur.

Geologically, the region is principally Cretaceous and Cainozoic in age.

F.—ZONE OF PINKISH BROWN CALCAREOUS SOILS OF THE NULLARBOR PLAIN DESERT SHRUB STEPPES: 16,900,000 ACRES.

A zone of Tertiary limestones in the south-east portion of Western Australia is associated with a desert shrub steppe and has been defined as one region and named the Nullarbor region.

27.—NULLARBOR REGION: 16,900,000 ACRES.

The region, which corresponds to Clarke's (1926) Nullarbor region, is a featureless plain carrying a sparse vegetation of low saltbush (*Atriplex*) and blusbush (*Kochia*). On the marginal areas a few small trees and shrubs such as cheese wood (*Pittosporum phillyraeoides*), acacias and melaleucas grow in dongas or shallow depressions, but on the plain proper along the Trans-Australian Railway Line nothing but the sparse saltbush and bluebush about one foot high is observed.

Although the plain appears perfectly flat, in actual fact is is very gently undulating and from the air appears pock-marked by shallow dongas.

The travertine seems to occur within a few inches of the surface and is covered by a layer of pinkish brown calcareous material of a loamy to clayey texture, which may be described as soil. Deflation appears to remove this material fast enough to maintain permanent immaturity. In 1930, four samples of soil were collected near Forrest by Mrs. Johnson (then Lecturer in Botany at the University of Western Australia) and examination gave the following results:—

Analyses of soil samples from the Nullarbor Plain at Forrest and from a tree belt 15 miles north of Forrest.

Serial No.	Depth.	Description.	Calcium Carbonate.	Salt (NaCl) from Cl.	pH. Quinhydrone, 1 : 5.	pH. Glass electrode, 1 : 5.
	inches.			%		
A271	0—6	Dark fawn silty clay	rich	0·07	8·50	8·88
A272	0—6	Fawn silty clay from bluebush area	rich	0·38	7·72	8·08
A273	0—6	Fawn silty clay from *Trigonella* clover area	rich	0·02	7·56	7·94
A274	0—6	Light brown silty loam from tree belt 15 miles north of Forrest	rich	0·007	8·06	8·62

The rainfall of the area is very low—probably averages between 5 and 10 inches per annum—and long drought periods severely tax the vitality of the vegetation. Following rains, a rich, ephemeral carpet of grasses and herbage appears.

The travertine is interesting as it contains small, black, globular inclusions unlike any other limestone formations yet observed in Western Australia. The nature and origin of these inclusions are at present unknown.

Ferruginous gravel or lateriate is not known to exist.

The pastoral possibilities of the region appear to the very scanty.

G.—ZONE OF PINKISH BROWN CALCAREOUS SOILS OF THE SEMI-DESERT SCRUB ASSOCIATED WITH THE NULLARBOR PLAIN—31,000,000 ACRES.

On account of the paucity of information this zone is mapped as one region and named the Giles region after Ernest Giles who traversed it in 1875 (Giles, 1889).

28.—GILES REGION: 31,000,000 ACRES.

West of Naretha, on the Transcontinental railway line, the vegetation changes to acacia scrub (mulga) with saltbush and bluebush as undergrowth. The soils resemble those of the Nullarbor region in being pinkish brown in colour and possessing a calcareous travertine in the subsoil. The surface soil, however, is deeper and probably reflects the protection of the vegetation and a slightly higher rainfall—probably about 9 to 10 inches per annum.

Giles describes the country further north as being covered with mallee scrub (*Euc. dumosa*), mulga (*Acacia* spp.), cypress-pine (*Callitris* sp.), *Casuarina* sp., quondong (*Santalum acuminatum*) and poplars (*Codonocarpus cotonifolius*) and an undergrowth of spinifex and shrubs. Blackboy (*Xanthorrhoea* sp.) is reported. The soil is apparently reddish and sandy, sandhill formations are common, and salt lakes of frequent occurrence.

The land classification of McLeod (1922) indicates that this belt of mulga, myall and some mallees, with an undergrowth of saltbush and bluebush, continues south of the Transcontinental railway and reaches the coast in the vicinity of Eyre. It also forms a buffer region between the Nullarbor Plain and the south coast in Western Australia.

It seems likely that the soils of the Giles region resemble those of that portion of South Australia north and east of the Nullarbor Plain. They certainly form a soil zone quite distinct from the more western portions of Western Australia in the same vegetation and climatic belt. In fact, the soils of the Giles region show a closer affinity to those of the Nullarbor region than of other regions recognised.

Laterite is not known to occur.

The pastoral possibilities of the northern portions of the Giles region are largely unknown, but difficulties in obtaining suitable water supplies probably present the chief problem. It is recognised that the coastal portions of the region carry some of the finest pasturage of the low rainfall areas of the State but the prevalence of brackish water renders appropriate pastoral development difficult.

McLean (1926) reports the analyses of two samples of water from between Eucla and the Transcontinental line as follows:—

Sample.	Magnesium.	Salt (NaCl).	Total water soluble salts.
	grains per gallon.	grains per gallon.	grains per gallon.
1	36·4	818·6	961·2
2	36·4	818·6	963·2

The narrow fringe of coastal country between the limestone cliffs and the sea carries mallee and could be considered as part of the zone of grey and brown calcareous solonised soils of the eucalyptus woodland. However, the wealth of saltbush and bluebush conveniently associates it with the southern part of the Giles region and for that reason this strip is included with the Giles region.

H.—THE BROWN SOIL ZONE OF THE NORTHERN TROPICAL WOODLANDS, SAVANNAHS AND GRASSLANDS: 79,600,000 ACRES.

Our knowledge of the soils of the tropical areas is very meagre but a general picture of the zonal features has been obtained as a result of a visit by Prescott (1937). In addition, a number of geological, botanical and agricultural expeditions* have been made and these, together with the recent reports of Surveyors H. Barclay, S. J. Stokes, and T. Cleave, afford a general picture of the area.

The main mass consists of a dissected and eroded plateau, or conoplain to use Jutson's term (Jutson (1934), p. 42), generally 1,000 to 2,000 feet in elevation. On the north is a rugged, becliffed coastline, with huge gulfs and indentations, and rivers running in deep gorges with wall-like sides. The west, south and east boundaries of the conoplain are delineated by the King Leopold Ranges, the Albert Edward Range, and the Carr Boyd Range. Outside of these boundaries is a lower and much more highly eroded plateau. The valleys of the various rivers in this latter area are most important pastorally and it is here the zonal soil type has developed. The chief rivers are the Fitzroy, Lennard, Robinson and Ord systems.

The geological formations of the conoplain are mainly massive Precambrian sandstones and lava flows probably of the Nullagine series. It is fringed on the west, south and east by Mosquito Creek formations. A mass of granite is sandwiched between these two sedimentary series on the south-east. Wade (1936) reports that the most important group of sedimentary rocks in the south-western portion of the zone (West Kimberley area) belongs to the Permian System and is regarded as a likely source of oil. Devonian limestones also occur extensively in this area and rest, with marked unconformity, on the Precambrians. The Cape Leveque Peninsula and south-western coastal areas are Jurassic in age. On the extreme east, the limestones and basalts of the Antrim Tableland are of Cambrian age.

Prescott (1937) has summarised the climate and vegetation characteristics. A study of the available records shows that the rainfall is markedly seasonal and practically confined in incidence to the summer months. The

* Easton, Fitzgerald, Brockman, Wise, Evans & Lefroy, Payne.

rainfall per wet day is high (about 0.50 inches) and both this factor and the length of the wet season decreases from north to south. The most important, and unfortunate, feature of the rainfall is its variability, which is approximately twice as great as in parts of Northern Nigeria, for instance, where the climate is otherwise similar, but a large population is supported.

Prescott quotes the following information:—

Centre.	Mean annual rainfall.	Proportion of rain falling Oct.–Mar.	Rainfall per day.	Length* of wet season.
	inches.	per cent.	inches.	months.
Port George IV.	53·9	91	0·63	5·2
Drysdale River	36·1	91	0·52	5·2
Ivanhoe	32·8	94	0·62	4·1
Wyndham	26·9	94	0·44	4·2
Argyle Downs	26·1	94	0·50	4·0
Derby	25·8	88	0·55	4·2
Broome	23·0	85	0·56	4·1
Hall's Creek	20·8	91	0·36	3·0
Ord River	19·9	94	0·45	3·4
Noonkanbah	19·2	92	0·49	3·0

* Length of wet season is taken as the period during which the monthly ratio of rainfall to saturation deficit exceeds the value of 5.

Davidson (1934) estimates that, except in the extreme north, precipitation exceeds evaporation in January and February only.

The high rainfall per wet day and the occurrence of torrential rains are important factors in the degree of leaching of the soils which do not appear to be generally calcareous except where the texture is heavy or special geological formations occur.

Gardner (1923) has described the principal vegetation associations of the zone. In brief, they may be summarised as follows:—

(1) *Rain or Corridor forests.*

Fringing the rivers of the Brockman and Drysdale regions are strips, up to 200 yards wide, of moist black soils. The moisture persists throughout the dry period and a dense rainforest, practically devoid of eucalypts, has become established. The Leichardt tree (*Sarcocephalus*), the banyan and other species of *Ficus*, a kapok tree, cajuput (*Melaleuca leucadendron*), etc., are characteristic. Mangroves flourish in the soft, black mud of the coastal areas.

(2) *Sclerophyll forests or woodlands.*

In the Drysdale region, away from the water courses, a typical sclerophyll forest association, resembling the jarrah forest of the south-west in general appearance, has established in the lateritic and skeletal soils. The chief trees are messmate (*Eucalyptus tetrodonta*), ironbark (*Erythrophleum chlorostachys*), stringy bark (*Euc. tetrodonta*), woollybutt (*Euc. miniata*), pindan wattle (*Acacia tumida*), *Jacksonia* spp., *Grevillea* spp., Pandanus, and fan palms (*Livistona*). Soft spinifex and some grasses are reported.

(3) *Savannah woodlands.*

Probably the savannah woodlands are the most important and extensive vegetation associations of the zone. Two main types occur.

(a) Undulating basaltic country. Open woodlands of grey box or coolibah (*Euc. microtheca*) are most characteristic and bloodwoods (*Euc. pyrophora* and *Euc. terminalis*) are fairly common.

With these trees, fine grasses, such as Flinders grass (*Iseilema membranacea*) and kangaroo grasses (*Themeda* spp.) grow in profusion.

(b) Sandstone country.

This is largely steep scarps and ranges and carries a denser vegetation including cypress-pine (*Callitris intratropica*), messmate (*Eucalyptus tetrodonta*) and woollybutt (*Euc. miniata*). The "grasses" are of a coarser and poorer type. Sugar grass (*Andropogon* sp.), spinifex (*Triodia*) and *Cyperaceae* are common.

(4) *Low tree savannah woodlands.*

The sandy soils of the pindan* areas commonly carry a scattering of more or less stunted trees, for example, a bloodwood, and a dense undergrowth of pindan wattle (*Acacia tumida*), such shrubs as konkerberry (*Carissa*), an ironwood (*Terminalia circumalata*), and coarse grasses such as *Andropogon* spp.

(5) *Grasslands and savannahs.*

Pastorally the grassland and savannah associations are of very considerable importance. They occupy the heavier textured soils generally, which do not appear to favour trees, and appear to predominate where the rainfall is lower or is physiologically lower on account of soil texture.

Three types of association may be mentioned in this group.

(a) Open grasslands, almost devoid of trees, are characteristic of the heavier textured brown and "black" soils of the plains. Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), kangaroo grasses (*Themeda* spp.), and bundle bundle are the chief grasses, and *Bauhinia Cunninghamii* is probably the most characteristic tree. Gutta-percha (*Excaecaria parvifolia*), a small tree, is common on the heaviest soils where the water supply is adequate.

(b) Dense cane grass (often up to 10 to 14 feet tall) and sugar grass (*Andropogon affinis*) grow on the sandier slopes.

(c) Spinifex (*Triodia* spp.) is characteristic of the stony range country receiving less than 30 inches of rain per annum and of the soils generally where the rainfall is low and restricted to about three months of the year or less.

The Soils.

Until Prescott's visit (1937) the zonal relationships of these soils were obscure. He recognised a similarily between the zonal soils of this area and of the Murray valley and has tentatively proposed to group them with the grey and brown, and "mallee" soils of the south, which are essentially alkaline and calcareous. It seems to the writer that more evidence is needed

*Pindan is a native name referring to the land away from the rivers and permanent water.

to establish such a general relationship, as a body of information points to a higher degree of leaching and a lower degree of alkalinity than is exhibited by the soils of the semi-arid south.

The reactions of a number of samples from the zone, including a profile examined by Prescott (1937) at Noonkanbah Station, are shown in the following distribution table:—

——	Number of samples in each range.									
Range, pH	5·2—5·6	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8	above 8·8
Surface	2	3	...	2	1	1	3	2	....	..
Subsoil	.	4	5	....	....	2	1	2	2	1

The number of acidic soils is of considerable interest in discussing the affinities of the soils of this zone.

Competent observers agree that the principal soils are of the brown type. Surveyor Cleave (private communication) has likened the soils of the peninsula south of Yampi Sound to the red brown earths at York. Surveyors Barclay and Stokes have made similar observations along the Northern Australia boundary and Dr. A. Wade of the Freney Kimberley Development Company mentions brown soils on certain basaltic plateaux and on the "blue clay" geological horizon in the Oscar Range district.

The brown soils appear to fall into four groups—

(a) The heavy textured soils of the river terraces which resemble the heavier soils of the Murray and Murrumbidgee valleys. Prescott describes one profile at Noonkanbah as being uniformly brown in colour, cloddy in structure, slightly calcareous in the subsoil and highly gypseous below 35 inches. These soils carry a grassland or open savannah association.

(b) The reddish sandy soils—the so-called "pindan" soils. These soils show a low east-west sandhill formation and are densely covered by the low tree savannah woodland associations. They provide accommodation for stock during the "wet" season.

(c) Brown clayey soils of the "blue clay" geological horizon of the Oscar range district and on certain basaltic formations (described by Dr. A. Wade).

(d) Brown sandy loams and loamy sands of the savannah woodlands Cleave (private communication) has described these in the valleys of the peninsula south of Yampi Sound as more or less stony sandy loams carrying a woodland of grey box (*Eucalyptus ? Spenceriana*), woollybutt (*Euc. miniata*), white gum (*Euc. papuana*) and cajuput (*Melaleuca leucadendron*) with abundant grasses and shrubs and small trees such as konkerberry (*Carissa*) and cotton tree (*Cochlospermum heteroneurum*).

Intrazonal soils are black soils of certain valley formations in the Ord Valley, on Cambrian basalts of the Antrim tableland and occasionally on basalts of the Brockman region, and on Devonian limestones in the Oscar Range (Dr. A. Wade). These black soils typically carry good quality and, also, coarse grasslands or open savannahs, and are of very heavy texture. During the dry season they crack badly and often open up into crevices 6 inches wide and 3 feet deep. However, many of the popularly described "black" soils undoubtedly belong to the brown soil group. Yellow and greyish yellow and yellow brown sands, often with ferruginous gravel (laterite) in

the subsoil, constitute another important intrazonal soil type. An extensive area of this type, 30-40 miles across, occurs south-east of Wyndham. Barclay (private communication) reports this to be vegetated by a type of *Melaleuca* resembling *M. thuyoides* in habit. Similar sandy soils were observed on the Border Survey.

Areas of restricted drainage are associated with light grey to yellowish grey powdery and loamy soils generally associated with cajuput (*Melaleuca leucadendron*) in the west and with spinifex and scattered trees in the east. The grey anthills of these soils are most characteristic.

Other intrazonal soils are the moist black soils of the corridor rain forests of the northern river gorges, the red basaltic soils described by Easton and observed by Barclay on the Antrim Tableland, and the buff soils of the moving sandhills. Wade (private communication) has observed that the soils of the fixed sandhills are characteristically red in colour but where movement is taking place the soils are a buff colour.

Laterite is a prominent feature in many parts of the zone but particularly in the Drysdale region of the north. Fitzgerald (1907) records ferruginous gravel in the pindan country of the May River east of Derby and in the Throssell River, the Isdell Range and the Sprigg River areas in the conoplain (Hann region). Cleave (private communication) mentions an occurrence of lateritic material on the Townshend River, Oobagooma Station, near Derby.

A sample of the yellowish sandy soil type collected by Surveyor S. J. Stokes on the border survey showed a subsoil rich in pisolitic, ferruginous gravel of the laterite type. Similar profiles are common in the southern temperate part of the State.

By far the most extensive intrazonal soils are of the skeletal group. The rough range country, which is typified by the Hann region, is typically eroded, and rough, stony skeletal soils are the main formation. It is the occurrence of these soils which largely limits the development of the Kimberley Districts as they are of low fertility and support a woodland vegetation of low pastoral value.

On the sandstones and quartzites, which Easton estimates to occupy over 70 per cent. of the area of the range country, the soils appear generally to be of a grey colour. However, brown skeletal soils have been described by Cleave in his observations in the peninsula south of Yampi Sound. These belong to the brown soil group.

The zone is predominantly a pastoral country. Early development was practically entirely for cattle which took advantage of the coarse growing grasses and was largely confined to the Fitzroy region where the topography presented no serious difficulties. Some development has proceeded in the Hann region in localities where soil and topographic features are more propitious but the conoplain generally is too rough and the soils inadequate for pastoral activities.

Sheep raising is assuming greater importance as the development has proceeded and more adequate water provision is made. A number of important stations on the Fitzroy River, for example, Noonkanbah, are successfully engaged in wool production. It is thought that there will be further expansion in the sheep industry in the Kimberleys in the future.

Practically no agricultural activity is reported from the zone. Various estimates of the extent of agricultural land have been made. Fitzgerald (1907) estimated that over a million acres of country were suitable for the cultivation of tropical products. There is no doubt that areas of suitable agricultural soils exist in this soil zone but development is rendered difficult by such factors as variability of the rainfall, climatic conditions unattractive to a white population, and, to a lesser extent, accessibility to markets and supplies.

The brown soil zone of the tropical savannahs and grasslands has been divided into four soil regions, largely on the basis of physiographic and geological factors. Two of these regions, the Brockman and Drysdale regions, might possibly be considered as sub-regions of the Hann Region.

29.—FITZROY REGION: 39,900,000 ACRES.

The Fitzroy region is occupied by the main river basins, and the low dissected plateau of the southern, eastern and western portion of the zone. The soils have developed zonal features and are the basis for the classification of the main soils of the north of the State. Brown soils predominate and carry the chief pastoral activities of the north. Grassland associations, savannahs and savannah woodlands are the predominant ecological features.

In an earlier regional classification this region was divided into two. The western portion, including the Leveque Peninsula and the coastal country west of Broome, was separated as a region on account of the predominance of sandy country of the "pindan" type. Later consideration showed that this type is common throughout the region and the definition of another region seems undesirable in the light of our present scanty knowledge.

The Antrim Tableland east of Hall's Creek could be considered as a region but paucity of appropriate information renders it advisable not to attempt subdivision at the present time.

Little is known of the chemical nature of the soils. Analyses made by the Government Chemical Laboratory about 20 years ago showed them to be somewhat low in plant foods (Tables 15 and 16) but the pedological, pastoral or agricultural significance of these results is obscure. Recent analyses of 3 samples from Ivanhoe Station in the Ord River valley have been made and are more informative.

The samples are described as follows:—

(1) "Red" soil of an open savannah carrying white gum (*Euc. papuana*), red gum (*Eucalyptus* sp.), cabbage gum (*Euc. clavigera*), native couch (*? Cynodon dactylon*), and kangaroo grass (*Themeda* sp.).

A2062, 0-9 inches deep, a chocolate brown micaceous, light fine sandy loam.

A2603, 9-18 inches deep, a rich brown micaceous, fine sandy loam.

(2) "Black" soil carrying Flinders grass (*Iseilema membranacea*) and Mitchell grass (*Astrebla pectinata*), and sparsely timbered with *Bauhinia Cunninghamii*.

A2064, 0-12 inches deep, a greyish chocolate light loamy clay (brownish, blackish grey when wet).

The analyses of these samples are given in Table 14.

TABLE 14.

Analyses of samples of soil from the Ivanhoe Station, Ord River, Kimberley, representing the Fitzroy Region.

Sample Number	A2062	A2063	A2064
Depth (inches)	0–9	9–18	0 12
Mechanical Analysis—			
Coarse sand %	3·8	5·2	4·5
Fine sand %	73·3	63·2	44·4
Silt %	8·5	9·7	12·8
Clay %	11·7	18·2	32·3
Loss on acid treatments % ...	0·8	0·8	1·3
Moisture %	1·6	2·1	3·7
Loss on ignition %	2·7	3·0	4·6
Calcium carbonate %	0·4	0·6	0·5
Chemical Analysis—			
Nitrogen %	0·056	0·050	0·062
Organic carbon %	0·595	0·344	0·764
Carbon : nitrogen ratio % ...	10·6	6·9	12·3
pH (1 : 2½, quinhydrone) ...	7·05†	7·49	7·24
*Potash, K_2O %	0·396	0·383	0·413
*Phosphoric oxide, P_2O_5 % ...	0·036	0·021	0·020
Replaceable Bases —			
Total—m.e. per 100 gm. soil ...	11·75	13·29	24·13
Total bases m.e. per 100 gm. clay	100	73	75
Calcium—percentage of total rep. bases	57	54	50
Magnesium—percentage of total rep. bases	37	40	46
Potassium—percentage of total rep. bases	5	4	3
Sodium—percentage of total rep. bases	1	2	1
Replaceable Hydrogen—m.e. per 100 gm. soil	1·5	1·3	2·7

*Soluble in concentrated hydrochloric acid. †Glass electrode, 6·79.

These samples indicate that the soils of these types are rich generally, but are low in phosphate.

Details of two interesting traverses in this region are available and may be summarised here:—

(1) Yampi Sound to Oobagooma Station—Surveyor T. Cleave:—

0-16 miles. Rough, quartzitic hills with a few granitic and basaltic outcrops. The valleys are narrow and very stony and carry a woodland of woollybutt (*Euc. miniata*), grey box (*Euc. ? Spenceriana*) and bloodwood. The area is well grassed and carries, in addition, a little soft spinifex. The soil is a brown sandy loam but is very stony and of the skeletal type.

16-30 miles. The valleys are wider—up to one mile—flat and well grassed, and carry a grey box woodland with konkerberry (*Carissa*) and cotton tree shrubs. In this section the soils are brown and light brown in colour and stony only in patches. Very rough, flat-topped, quartzitic hills are characteristic.

30-50 miles. This area includes the headwaters of the tributaries of the Robinson River. The valleys are flat, several miles wide, and broken by quartzitic mesas. Tall white gum (*Euc. papuana*) and cajuput (*Melal. leucadendron*) grow in the grassy valleys and grey box (*Euc. ? Spenceriana*) on the higher slopes. The soils are of the brown type.

The first 30 miles of this well watered country is reported to be too rough for pastoral development.

South of this section is encountered the pindan country with poor scraggy timber (wattle (*Acacia tumida*), cajuput, and beefwood) and yellowish to yellowish grey soils, more clayey than the brown soils above.

(2) Border survey—north coast to 294 miles south—along the 129° E meridian. (West Australian, November 22nd, 1937, reporting Surveyors H. Barclay and S. J. Stokes):—

0-15 miles—mud flats, mangrove belts.

15-16 miles—grassy country.

16-34 miles—dirty grey, loose sand carrying messmate (*Euc. tetrodonta*) and woollybutt (*Euc. miniata*).

34-38 miles—Weber Ra.—very rough quartzitic country.

38-58 miles—black soil plain with sparse timber and Flinders grass (*Iseilema membranacea*). The soil is a heavy clay and in the dry period cracks badly. The cracks may be as much as 6 inches wide and 3 feet deep.

58-69 miles—Burt Ra.: very rough and difficult sandstone range, 800 to 1,000 feet high.

69-81 miles—sandy country with deep creeks. Dense cane grass (*Rottboellia rottboellioides*) up to 12 to 14 feet tall.

78½ miles—Obelisk.

81-111 miles—black soil plain with basalt boulders and broken by basalt hills and ridges. Carries good Mitchell grass (*Astrebla pectinata*) and Flinders grass with cane grass and sugar grass (*Andropogon affinis*) on the slopes.

111-134 miles—dissected plateau country with very stony soils of the Behn River system—"red" soils reported.

134-158 miles—Negri River Plains and other plains with sandy stretches and ranges. The plains are badly affected by wind erosion—Probably brown soils.

158-165 miles—woodland of trees, grass and spinifex.

165-192 miles—limestone and basalt plateau. Rough dissected country with deep gorges and piled basalt boulders. Vegetation—largely thick matted spinifex.

192-208 miles—flat plain of greyish crumbly clay on a black hard clay which cracks badly when dry. Flinders grass is the chief grass.

208-235 miles—rolling country with spinifex and sparse acacia, leading to red gritty soil with a hardpan said to resemble coffee rock. This type carries mallee types of eucalypts and *Melaleuca* scrub as well as spinifex.

235-245 miles—open downs.

245-294 miles—sandy ridges and sandy troughs.

294 miles southwards—a sandstone range carrying spinifex, mallee eucalypts, and sparse acacias.

The occurrence of hardpan in the red gritty soil of the 208-235 mile section is of interest and suggests a possible relationship with the hardpan soils of the acacia semi-desert scrub zone.

30.—HANN REGION: 28,900,000 ACRES.

The Hann Region consists of a series of ranges and tablelands with intervening plains, and forms a low dome or conoplain. Sandstones and quartzites are the chief rocks but areas of basaltic intrusives occur. The area is dissected by streams and gorges and is exceptionally rough, but the plains, often quite extensive, are suitable for pastoral development where accessible. The chief vegetation association is the savannah woodland which has been described above (page 178).

Little is known of the soils except that they are predominantly skeletal. Grey soils appear to occur on the sandstones and quartzites, but red and black soils are described on the basaltic rocks. Brown soils should be the normal type.

31.—BROCKMAN REGION: 5,000,000 ACRES.

Between Walcott Inlet and Prince Frederick Harbour and inland as far as Mount Agnes and Mount Hann lies a region of fairly high rainfall (33 to 50 inches per annum) and in which the very rough sandstone country is intersected by deep gorges with wall-like sides.

In these gorges run rivers of considerable magnitude and associated with these rivers are strips of moist black soils carrying the "corridor" rain forests. In other respects the conditions appear to resemble closely those of the Hann region. The soils are largely skeletal in type but brown soils should be the "normal" type. Semi-humid red soils should occur in the wetter parts of the region but have not been observed.

32.—DRYSDALE REGION: 5,800,000 ACRES.

The extreme northern portion of the zone is likewise more generously provided with rain (33 to 40 inches per annum) but differs from the Brockman region in the occurrence of much ironstone gravel—undoubtedly laterite—with the sandstone formations. The sclerophyll woodland (see page 177) of the Drysdale region is a further regional distinction. The region forms an extension of the very rough sandstone tableland with basaltic flows of the Hann and Brockman regions and is deeply cut by river gorges.

Little is known of the soil conditions except that laterite gravel is common and that skeletal soils occupy the bulk of the area. Red soils would be expected in the wetter portions of the region but the normal soils generally should be of the brown type.

I.—THE ZONE OF RED SANDS OF THE CENTRAL DESERT SANDHILLS—143,000,000 ACRES.

The central eastern portion of the State may justly be described as desert. As with other great deserts of the world, it is by no means uninhabitable, but, at the present time, the population is restricted to nomadic abori-

ginals. The climate is certainly desertic but details of the conditions are unknown. The average annual precipitation is probably between 5 and 10 inches and the variability is most probably high. Summer temperatures are high and winter temperatures mild in comparison with most continental climates as it is likely that minima rarely fall below 20° F.

Geologically the strata range from the ancient Nullagine Series and probably Mesozoic or Tertiary formations of the central and southern portions to Permian series in the north-west section. Over most of the area the rocks are covered by rolling spinifex covered sandhills but scattered outcrops and breakaways break the monotony. Artesian water is reported in the Permian structures and here, too, there is a likelihood of occurrence of oil-bearing strata.

Clarke (1926) has divided this zone into two natural regions which he has named Carnegie and Canning, respectively. The Canning region occupies the Permian area where artesian as well as surface water may be obtained As the soil and vegetation conditions appear to be similar throughout the zone it has been here regarded as one region and is named the Carnegie region in honour of D. W. Carnegie (1898), the first explorer to traverse it thoroughly.

33.—CARNEGIE REGION: 143,000,000 ACRES.

This area of rolling, red sand dunes, fixed by spinifex and desert gums, proved very formidable to early explorers but has more readily yielded to later investigations aided by modern equipment. Carnegie (1898) was one of the early explorers and has very graphically described his experiences and the nature of the country. His book leaves an indelible impression of an interminable sea of parallel red sandhills. A little mulga and such plants as parakelia (*Calandrina* spp.) may grow in the troughs and spinifex and desert gums on the ridges. A few meagre native soaks and gnamma* holes appeared to be the only water supply. Talbot (1928) has described the country along the Canning Stock route in the north-western portion of the region. As representative of the area may be cited the country north and east of Lake Disappointment. Here the sandhills run East South East and West North West and are covered by spinifex and a light desert scrub and some mulga and poplar. Bloodwood (*Eucalyptus ? lamprocarpa*) occurs on some of the flats and mulga on the stony slopes of breakaways and hills. He mentions the Runton Range of steep red sandhills as much as 100 feet high. Canning was very successful in finding water along the stock route:—

Well No.	Depth.	Supply.	Value for Stock.
	feet.	Gal. per hour.	
6	11½	1,800	First class.
7	70	160	Excellent.
8	60	550	Good.
9	14	1,360	Good.
10	70½	250	Good.

Observations concerning the country in the vicinity of the Rawlinson Ranges, Mt. Carnegie and Bonython Range have been made by Ellis of the Western Australian Geological Survey (private communication). It is

*Gnamma holes are small holes in rocks which hold water. *See* Jutson (1934), p. 307.

described as a plain about 2,000 feet above sea level, with ranges up to 600 feet above the level of the plain scattered through it. The plain consists largely of red sand ridges about a quarter of a mile apart and carrying spinifex and *Eucalyptus eudesmoides* on the ridges. In the intervening depressions the typical plants are desert oak (*Casuarina Decaisneana*) and occasional patches of mulga where the soil is harder and more loamy in texture.

For a distance of 8 to 10 miles around the ranges the soil and moisture relations appear better, as mulga is more prevalent and becomes dominant on the alluvial outflows. With the mulga may be observed spinifex, grasses, and, sometimes, kurrajong. Whitewash gum (*Eucalyptus papuana*) is typical of the larger valleys and outwashes. Small patches of saltbush country may, at times, be encountered.

The ranges are largely of Nullagine quartzites indurated on the surfaces. The typical tops resemble residuals of an old peneplain formation. No evidence of laterite or of the Murchison Region hardpan was observed.

A number of salt lakes are known to occur in the region but further details are needed before any description could be attempted.

Talbot (1928) has observed that the sand is moving in a west and north-west direction and is piling up on the east and south east sides of the hills. From this, he concludes that the Carnegie region is gradually extending westward.

Except in the north-west coastal areas, the pastoral possibilities of the area appear to be very unpromising and mineral wealth has not been indicated by geological surveys.

VI.—RECAPITULATION.

In order to systematise the information available concerning the soil and ecological conditions of Western Australia, the State has been subdivided into 9 soil zones, or main soil groups, and 33 regions. The majority of the soil zones are representative of Australian-wide formations but at least two, the red and brown acidic soils of the acacia semi-desert scrub and the brown acidic soils of the semi-desert steppes, appear to be largely restricted to Western Australia. Further subdivision of the soil zones into regions on the basis of topographic, vegetation and soil features has led to the recognition of 33 regions. In each region these conditions are generally similar and, in consequence, agricultural and pastoral activities and problems will be grouped into similar divisions.

A general and ecological description of each region has been given. In the broadest outline, this information may be summarised as follows:—

A. *Zone of grey, yellow and red podsolised, or leached, soils of the temperate sclerophyll forests*—12,930,000 acres (page 129).

1. Swan littoral region: Jarrah, marri, wandoo and tuart sclerophyll forests of the coastal plain—4,400,000 acres (page 131).

2. Darling peneplain region: Jarrah, marri and wandoo sclerophyll forests of the Darling Ranges—3,900,000 acres (page 136).

3. Frankland region: Karri, jarrah and marri wet sclerophyll forests and wet heaths of the south coastal areas—4,630,000 acres (page 137).

B. *Zone of red brown earths of the eucalyptus—acacia woodlands*—27,460,000 acres (page 140).

4. Dwarda region: Yellow, grey and brown gravelly soils of the wandoo sclerophyll woodland—4,600,000 acres (page 142).

5. Irwin region: red brown soils of the york gum and jam woodlands and sand heaths—7,950,000 acres (page 143).

6. Avon region: red brown and grey soils of the york gum and jam woodlands—also wandoo, mallet, yate, salmon gum and morrel soils—6,700,000 acres (page 144).

7. Stirling region: grey and brown soils of moort, wandoo and yate woodlands, mallee and sand heaths—2,800,000 acres (page 146).

8. Eyre region: grey sand heaths and gravelly soils of the south coastal areas—5,410,000 acres (page 146).

C. *Zone of grey and brown calcareous, solonised soils of the low rainfall eucalyptus woodlands* ("mallee" soil zone of Prescott)—73,100,000 acres (page 149).

9. Corrigin region: grey and brown soils of salmon gum, gimlet and morrell woodlands, mallee and sand heaths—5,400,000 acres (page 154).

10. Merredin region: brown, red brown and grey soils of similar vegetation associations—7,900,000 acres (page 155).

11. Fitzgerald region: grey and brown soils of salmon gum, gimlet, morrel and redwood woodlands, mallee and sand heaths—11,900,000 acres (page 155).

12. Coolgardie region: brown, red brown and grey soils of the salmon gum, gimlet, morrel, blackbutt and salt bush woodlands and sand heaths—23,000,000 acres (page 157).

13. Zanthus region: brown and grey soils of the salmon gum, gimlet, morrel and redwood woodlands with salt bush, blue bush and sage bush—14,500,000 acres (page 158).

14. Ninghan region: brown and red brown soils of the salmon gum, gimlet, morrel, and york gum woodlands and sand heaths. Hardpan is a common feature of many soil types—7,600,000 acres (page 159).

15. Hartogs region: brown and red brown soils, carrying various eucalypts and acacias, and sand heaths—2,800,000 acres—(page 159).

D. *Zone of red and brown acidic soils of the acacia semi-desert scrub-mulga, etc.*—204,000,000 acres (page 160).

(a) Regions of hardpan soils—164,000,000 acres:

16. Murchison region: red and brown serir, hardpan soils of extensive mulga plains, with scattered ranges and hills—43,800,000 acres (page 163).

17. Yalgoo region: undulating country of brown and red brown serir, hardpan soils and lateritic types—19,100,000 acres (page 164).

18. Barlee region: red and brown hardpan soils of the mulga scrub, spinifex plains and saltbush-bluebush plains—44,100,000 acres (page 165).

19. Warburton region: red and brown soils transitional with the desert sandhill zone:—Spinifex covered plains and sandhills, mulga ranges and flats—57,000,000 acres (page 167).

(b) Regions without general development of hardpan—40,000,000 acres:

20. Gascoyne region: red and brown stony soils of hilly formations carrying mulga, grasses, etc.—13,500,000 acres (page 168).

21. Minilya region: red and brown soils of a sandhill formation and coastal country—7,400,000 acres (page 168).

22. Ashburton region: red and brown soils transitional with the semi-desert steppe zone—spinifex hills, mulga slopes and valley grasslands—19,100,000 acres (page 169).

E. *Zone of brown acidic soils of the spinifex semi-desert steppes of the north-west*—36,600,000 acres (page 170).

23. Nullagine region: dissected plateau country carrying spinifex, grasses and scattered small trees—13,300,000 acres (page 171).

24. Warralong region: rolling plains and valleys carrying spinifex, grasses and various trees—6,800,000 acres (page 171).

25. Hamersley region: dissected tableland country—coastal grasslands, hilly spinifex country and valley grasslands—10,600,000 acres (page 173).

26. Lyndon region: undulating spinifex grasslands—5,900,000 acres (page 173).

F. *Zone of pinkish brown calcareous soils of the Nullarbor Plain desert shrub steppes*—16,900,000 acres (page 174).

27. Nullarbor region: sparse salt bush and blue bush plain—16,900,000 acres (page 174).

G. *Zone of pinkish brown calcareous soils of the acacia semi-desert scrub, mallee and salt bush-blue bush associations*—31,000,000 acres (page 175).

28. Giles region: sandhills and plains fringing the Nullarbor plain in Western Australia—31,000,000 acres (page 175).

H. *Zone of brown soils of the northern tropical woodlands, savannahs and grasslands*—79,600,000 acres (page 176).

29. Fitzroy region: soils of the main valleys and highly eroded plateaux—39,900,000 acres (page 181).

30. Hann region: rough, dissected, sandstone tableland largely of grey skeletal soils and characterised by a savannah woodland—28,900,000 acres (page 184).

31. Brockman region: high rainfall, coastal extension of the sandstone table-land with river gorges carrying rain forests—5,000,000 acres (page 184).

32. Drysdale region: similar to the Hann region but characterised by much ironstone, gravelly soil and sclerophyll forest—5,800,000 acres (page 184).

I. *Zone of red sands of the central desert sandhills*—143,000,000 acres (page 184).

33. Carnegie region: spinifex covered sandhills broken by ranges associated with belts of mulga, desert eucalypts, etc.—143,000,000 acres (page 185).

As far as possible, pertinent, available chemical data with respect to the soils of the several zones have been summarised in distribution and other tables (Tables 15, 16 and 17). This information is imperfectly treated on account of lack of sufficient time to determine weighted averages for each horizon of each site examined. It was necessary to consider each sample, and

not each horizon from each site, as a unit in the preparation of these tables. This treatment will not be as accurate as may be desired but the distribution figures will certainly show clearly the general chemical composition of Western Australian soils.

TABLE 15.

Distribution table showing the Phosphate and Potash status of Soils of Western Australia by Zones.

(Compiled from information obtained from Files 96/06, 2700/09, 238/17 and 2148/22 of the Department of Agriculture, Files 252/15, 52/18 and 23/20 of the Explosives and Analytical Department, Western Australia, Simpson & Teakle (1934), Teakle & Southern (1935), Hosking & Greaves (1936), Hosking & Burvill (1938), Kessell & Stoate (1938), Serial Nos. A2062-2076, and data from the Lake King and Salmon Gums soil surveys.

A.—PHOSPHORIC OXIDE (P_2O_5).

(Soluble in concentrated hydrochloric acid.)

Range—per cent. P_2O_5.		Number of Samples in each Range.						
		below ·01	·01—·02	·02—·04	·04—·06	·06—·08	·08—·10	above ·10
A.—Grey, yellow and red podsolised, or leached, soils	Surface	38	59	66	50	24	16	29
	Subsoil	**52**	**39**	**35**	**27**	**14**	**2**	**9**
B.—Red, brown earth zone	Surface	2	16	28	7	2	2	1
	Subsoil	**2**	**17**	**10**	**1**			
C.—Grey and brown calcareous solonised soils	Surface	15	16	14	3	5	1	1
	Subsoil	**42**	**17**	**7**	**10**	**3**	**1**	
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	....	2	2	....	6	5
	Subsoil	....	....	....	**2**	**3**	**4**	**1**
E.—Brown acidic soils of semi-desert steppes		....	1	6	4	1	....	1
H.—Brown soils—Fitzroy region		....	4	4	8	2	....	4
Sand and gravel heath and wodjil soils	Surface	....	5	1	....	....	....	....
	Subsoil	....	5	4	....	....	....	

B.—POTASH (K_2O).

(Soluble in concentrated hydrochloric acid.)

Range—per cent. K_2O.		Number of Samples in each range.							
		below ·01	·01—·03	·03—·05	·05—·10	·10—·30	·30—·50	·50—1·0	above 1·0
A.—Grey, yellow and red podsolised, or leached, soils	Surface	23	55	33	66	41	6	5	4
	Subsoil	**26**	**28**	**25**	**43**	**22**	....	**6**	**4**
B.—Red brown earth zone	Surface	1	5	6	25	12	7	4	
	Subsoil	....	....	**4**	**6**	**16**	....	**5**	
C.—Grey and brown calcareous, solonised soils	Surface	....	4	3	7	13	8	11	8
	Subsoil	....	**5**	....	**7**	**10**	**5**	**31**	23
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	....	....	....	4	6	5	
	Subsoil	....	....	....	....	**2**	**2**	**7**	....
E.—Brown acidic soils of semi-desert steppe		....	....	1	....	5	2	....	....
H.—Brown soils—Fitzroy region		....	4	2	3	3	9	....	....
Sand and gravel heath and wodjil soils	Surface	....	1	1	3	1	....	....	....
	Subsoil	....	....	**2**	**3**	**2**	**2**		

TABLE 16.

Distribution Table showing the Nitrogen and Calcium Status of Soils of Western Australia by Zones.

(Compiled from information obtained from Files 96/06, 2700/09, 238/17 and 2148/22 of the Department of Agriculture, Files 252/15, 52/18 and 23/20 of the Explosives and Analytical Department, Western Australia, Simpson & Teakle (1934), Teakle & Southern (1935), Hosking and Greaves (1936), Hosking & Burvill (1938), Kessell & Stoate (1938), Serial Nos. A2062-2076, and data from the Lake King and Salmon Gums soil surveys.)

A.—Total Nitrogen.

Range—per cent. N		Number of Samples in each Range.						
		Below ·01	·01—·03	·03—·05	·05—·10	·10—·30	·30—·50	Above ·50
A.—Grey, yellow and red podsolised, or leached, soils	Surface	1	16	21	70	96	24	10
	Subsoil	16	81	51	39	10	..	..
B.—Red brown earth zone	Surface	....	3	6	27	17	..	.
	Subsoil	....	11	14	8	....	....	..
C.—Grey and brown calcareous, solonised soils	Surface	....	18	11	14	12	..	
	Subsoil	3	56	25	9	....	....	.
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	2	4	10	3		.
	Subsoil	....	7	3	1	.		.
E.—Brown acidic soils of semi-desert steppes		....	2	4	7	1	.	
H.—Brown soils—Fitzroy region		3	1	2	7	6	2	1
Sand and gravel heath and wodjil soils	Surface	....	4	2			.	
	Subsoil	....	7	2	.	.		

B.—Calcium (CaO).
(Soluble in concentrated hydrochloric acid.)

Range—per cent. CaO		Number of Samples in each Range.							
		Below ·10	·10—·50	·50—1·0	1·0—2·0	2·0—5·0	5·0—10·0	10·0—20·0	Above 20·0
A.—Grey, yellow and red podsolised, or leached, soils		105	125	17	9	4	1	....	.
B.—Red brown earth zone		22	32	4	1	3	3	2	1
C.—Grey and brown calcareous, solonised soils	Surface	11	18	2	2	6	...	...	
	Subsoil	11	11	3	3	7	7	8	..
D.—Red and brown acidic soils of the acacia semi-desert scrub		1	3	4	....	....	.	..	.
E.—Brown acidic soils of semi-desert steppes		1	3	4	2	3	.		...
H.—Brown soils—Fitzroy region		5	4	2	1	3	1	2	1

Study of these data show the great variability of the soils of Western Australia. Some are exceptionally rich in most of the important constituents. The majority are exceptionally low in phosphate and the general response of pastures and crops to superphosphate suggests that the phosphate present is also of low availability. Western Australian soils are generally low in nitrogen and organic matter, apparently the result of the arid summer conditions and the type of native vegetation not favouring organic matter accumulation. In the heavier textured soils of the wheat belt and in orchards in the wetter districts, the nitrate-nitrogen status appears to be good. The woodland soils of the wheat belt are generally rich in potash but the light textured soils are less generously supplied although actual potash deficiency

TABLE 17.

Analyses of soils from wet and dry areas in the agricultural districts of Western Australia.

Data from Dr. Howell's Report.

—	—	—	Analyses—per cent. in the soil.								
			Humus.	Nitrogen.	P_2O_5.	K_2O.	available.		CaO.	$CaCO_3$.	NaCl.
							P_2O_5.	K_2O.			
Wet Areas	Surface ...	11 Samples ...	2·83	·151	·051	·114	·009	·016	·348	·251	·023
	Subsoil ...	15 Samples ...	1·22	·055	·035	·157	·003	·014	·180	·149	·016
Dry Areas ... ... (including sandplain and white gum soils)	Surface ...	15 Samples ...	·77	·051	·028	·307	·002	·020	·598	·769	·010
	Subsoil ...	24 Samples ...	·51	·031	·028	·416	·002	·027	2·727	4·729	·077

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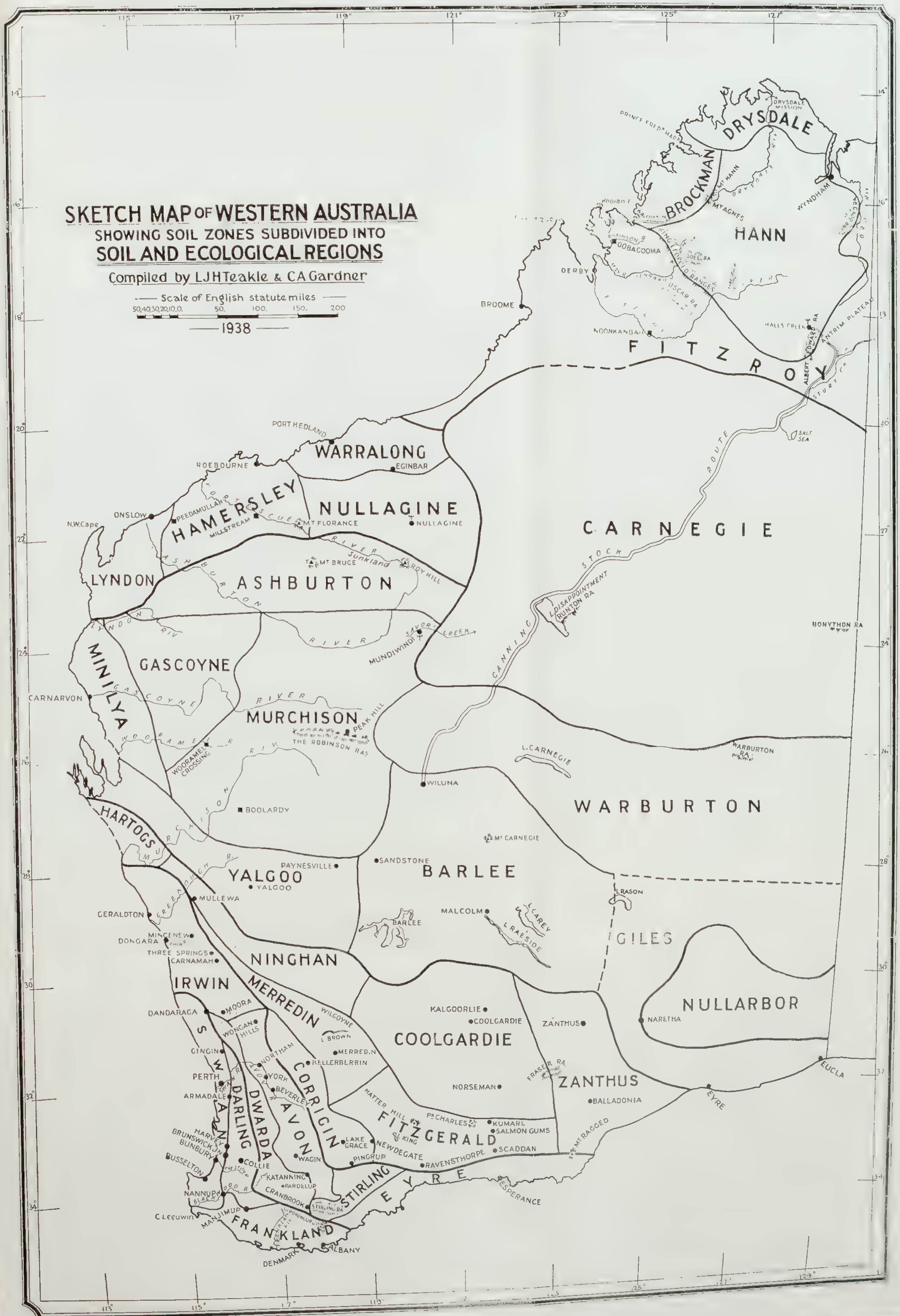
SKETCH MAP OF WESTERN AUSTRALIA
SHOWING SOIL ZONES SUBDIVIDED INTO
SOIL AND ECOLOGICAL REGIONS
Compiled by L.J.H.Teakle & C.A.Gardner
Scale of English statute miles
50 40 30 20 10 0 50 100 150 200
1938
DRYSDALE
BROCKMAN
HANN
FITZROY
WARRALONG
HAMERSLEY
NULLAGINE
CARNEGIE
LYNDON
ASHBURTON
MINILYA
GASCOYNE
MURCHISON
HARTOGS
WARBURTON
YALGOO
BARLEE
GILES
NINGHAN
IRWIN
MERREDIN
NULLARBOR
COOLGARDIE
ZANTHUS
SWAN
DARLING
DWARDA
AVON
CORRIGIN
FITZGERALD
STIRLING
EYRE
FRANKLAND
BROOME
DERBY
WYNDHAM
HALLS CREEK
PORT HEDLAND
ROEBOURNE
ONSLOW
N.W.Cape
CARNARVON
WILUNA
BOOLARDY
GERALDTON
MULLEWA
SANDSTONE
PAYNESVILLE
MALCOLM
KALGOORLIE
COOLGARDIE
ZANTHUS
NARETHA
NORSEMAN
BALLADONIA
EUCLA
EYRE
PERTH
BUNBURY
BUSSELTON
C.Leeuwin
ALBANY
DENMARK
ESPERANCE
RAVENSTHORPE
KATANNING
NARROGIN
WAGIN
YORK
NORTHAM
MOORA
DANDARAGA
GINGIN
COLLIE
CRANBROOK
MANJIMUP
NANNUP
CANNING STOCK ROUTE

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